



Bioremediation 4.0

The Power of Prokaryotic Bacteria
Quorum Sensing and Signaling (QSS)
& Organic Contaminant Destruction

TerraStryke Learning Program 23

Bacteria – History



Antoni van Leeuwenhoek 1632-1723



Founding Father of Microbiology



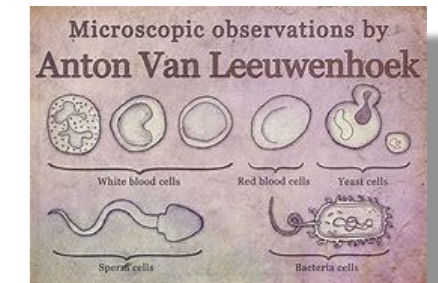
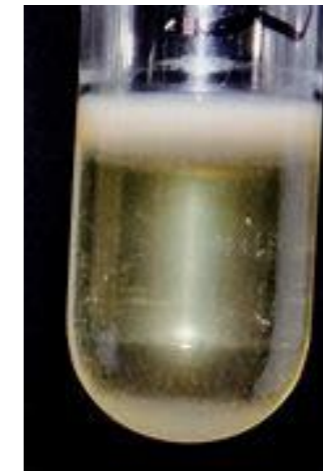
Identified planktonic bacteria – called them ‘Animalcules’ –



What he observed were protozoa, or ‘little animals’.



Also observed, after time, test tube solution gelled.



Bacteria – History



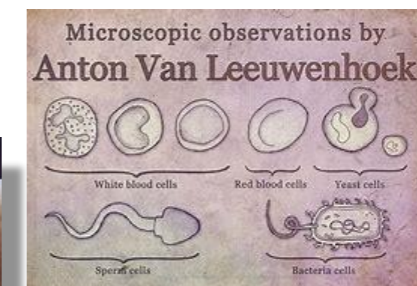
Late 1600's Leeuwenhoek noted biofilm bound bacteria.



Conveniently harvested from the plaque on his teeth.



Weren't aware of the complexity and prevalence of biofilm until the 1970s.



The Power of the Unicellular

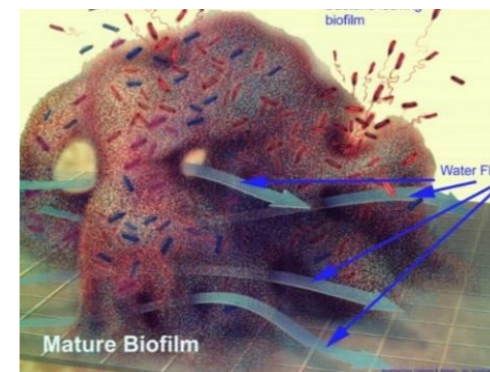
Historically believed

- ✓ Solitary
- ✓ Capable of little
- ✓ Swimmers key



We now have a completely different perspective

- ✓ < 1% of bacteria exist in planktonic form
- ✓ >99% of microbial populations live in biofilm
- ✓ Communicate ('talk'), share information, and recruit
- ✓ Determine what benefits the population
- ✓ Abandon individual roles for specific roles
- ✓ Establish structures like multi-cellular organism








What is a Biostimulation Strategy

At TerraStryke, we wholeheartedly believe that the **TREATMENT ZONE** needs to be viewed as an ecosystem that, **WHEN CONTAMINATED, IS UNDER DURESS** and can not support healthy microbes or QSS.

 **TERRA
STRYKE**

#bioremediation4point0

-  Enhance geochemistry and growth capacity of treatment zone
-  Support indigenous populations
-  Restores nutritive capacity of ecosystem
-  Maximizes microbial information sharing
-  Establishes greater bulk fraction of contaminant degraders



Biostimulation

What is *not* Biostimulation



Biostimulation

What *is* Biostimulation



Biostimulation

At TerraStryke, we wholeheartedly believe that the **TREATMENT ZONE** needs to be viewed as an ecosystem that, **WHEN CONTAMINATED, IS UNDER DURESS** and can not support healthy microbes or QSS.

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STRYKE**

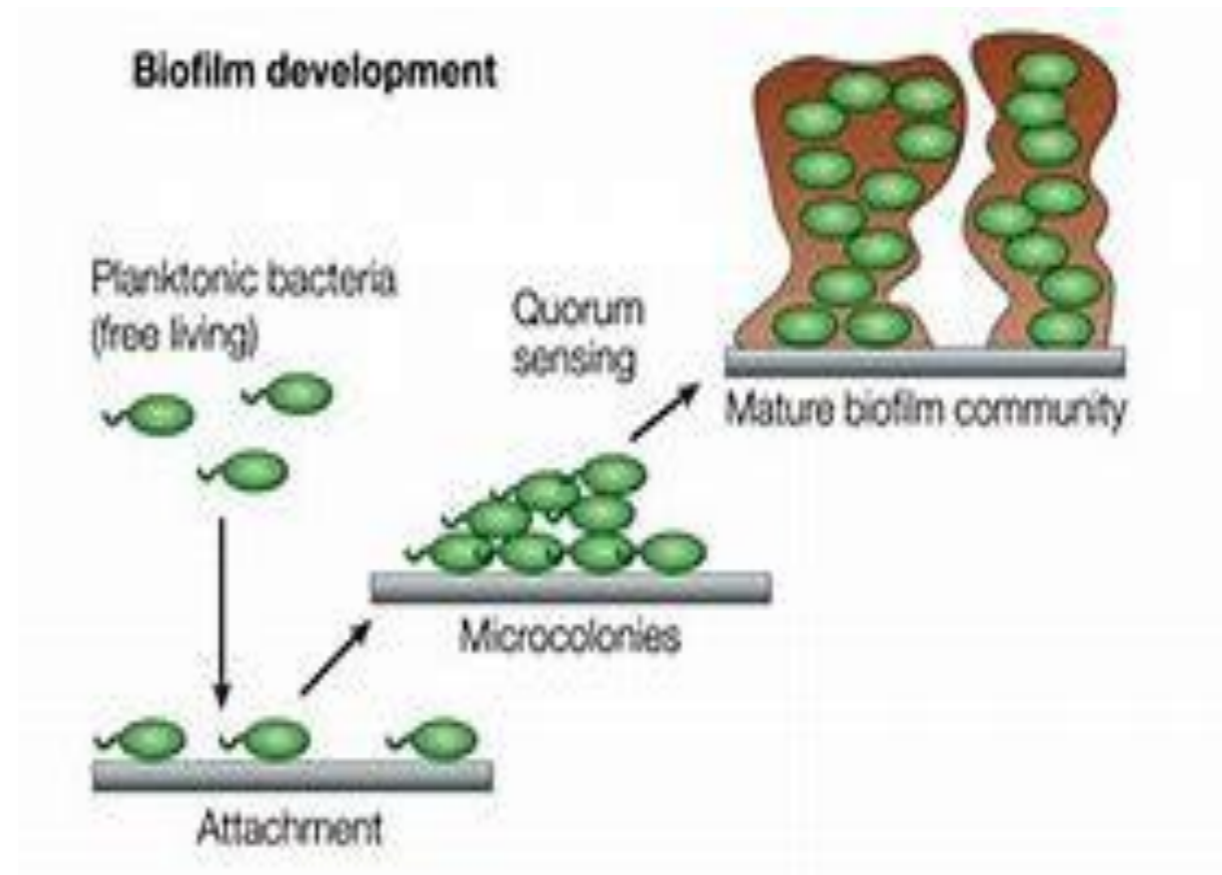
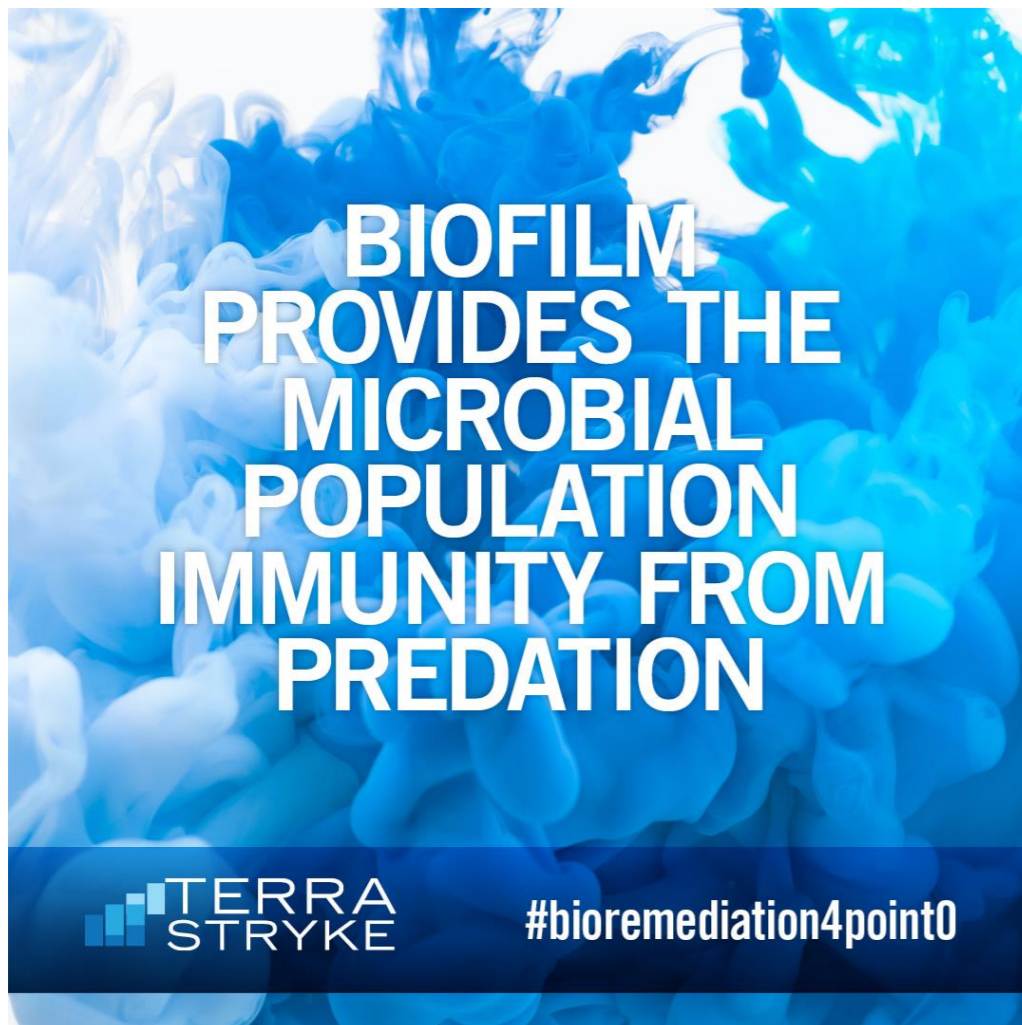
#bioremediation4point0

- ✓ Enhance nutritive capacity of treatment zone.
- ✓ Support indigenous populations
- ✓ Restores nutritive capacity of ecosystem.
- ✓ Allows microbes to collectively establish biofilms.
- ✓ Superior levels of sustainability, contaminant destruction with less impacts at lower costs.
- ✓ Most prevalent form of biology.

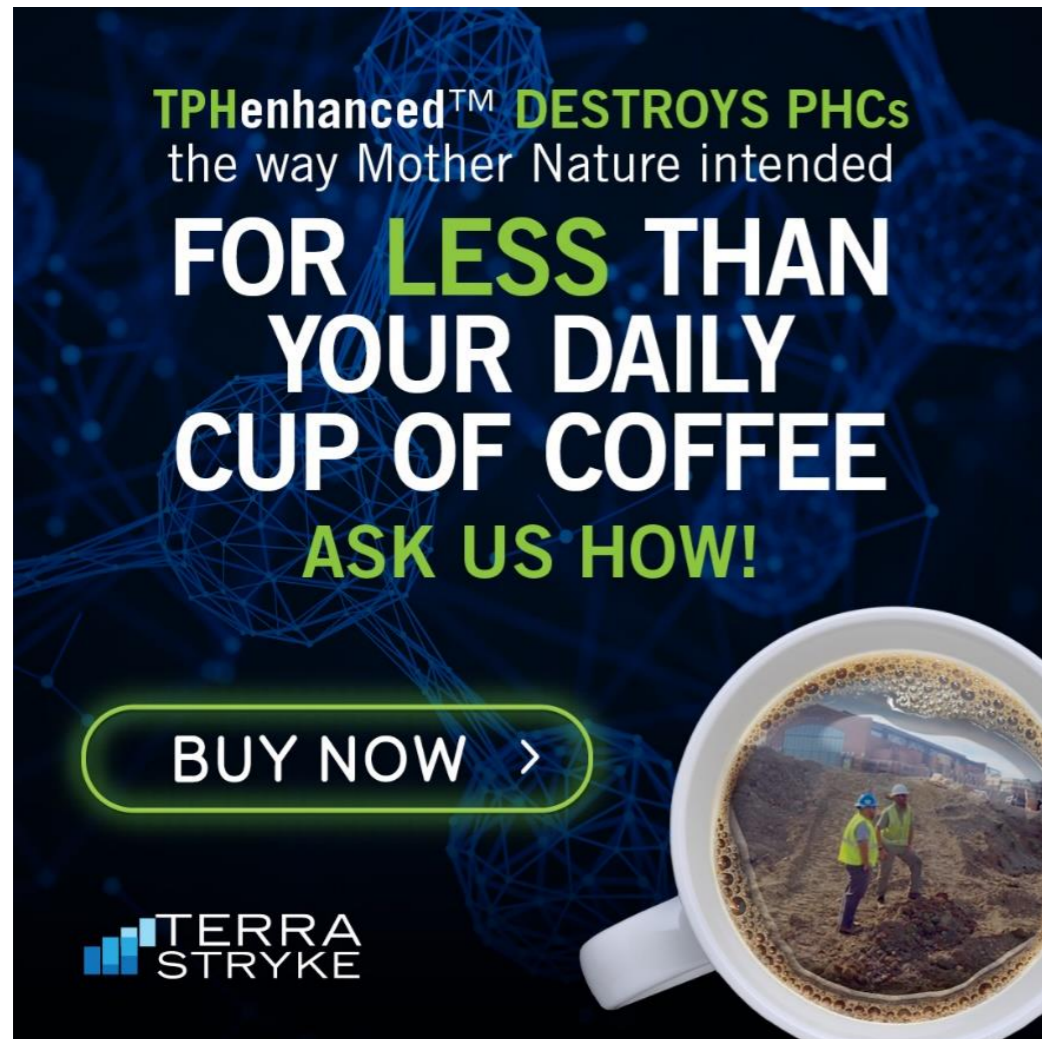


Biofilm

Biofilm development



Long-Chained Hydrocarbon Solution



TPHenhanced™ DESTROYS PHCs
the way Mother Nature intended

**FOR LESS THAN
YOUR DAILY
CUP OF COFFEE**

ASK US HOW!

BUY NOW >

**TERRA
STRYKE**

TPHenhanced™

**Passive-Aggressive
Residual Contaminant Mass Destruction**

Enhances respiration of heterotrophic bacteria under anaerobic conditions.

Organic strategy to contaminant destruction.

Proprietary macro-micro nutrient formulation package with nitrates to support ecosystem and respiration.

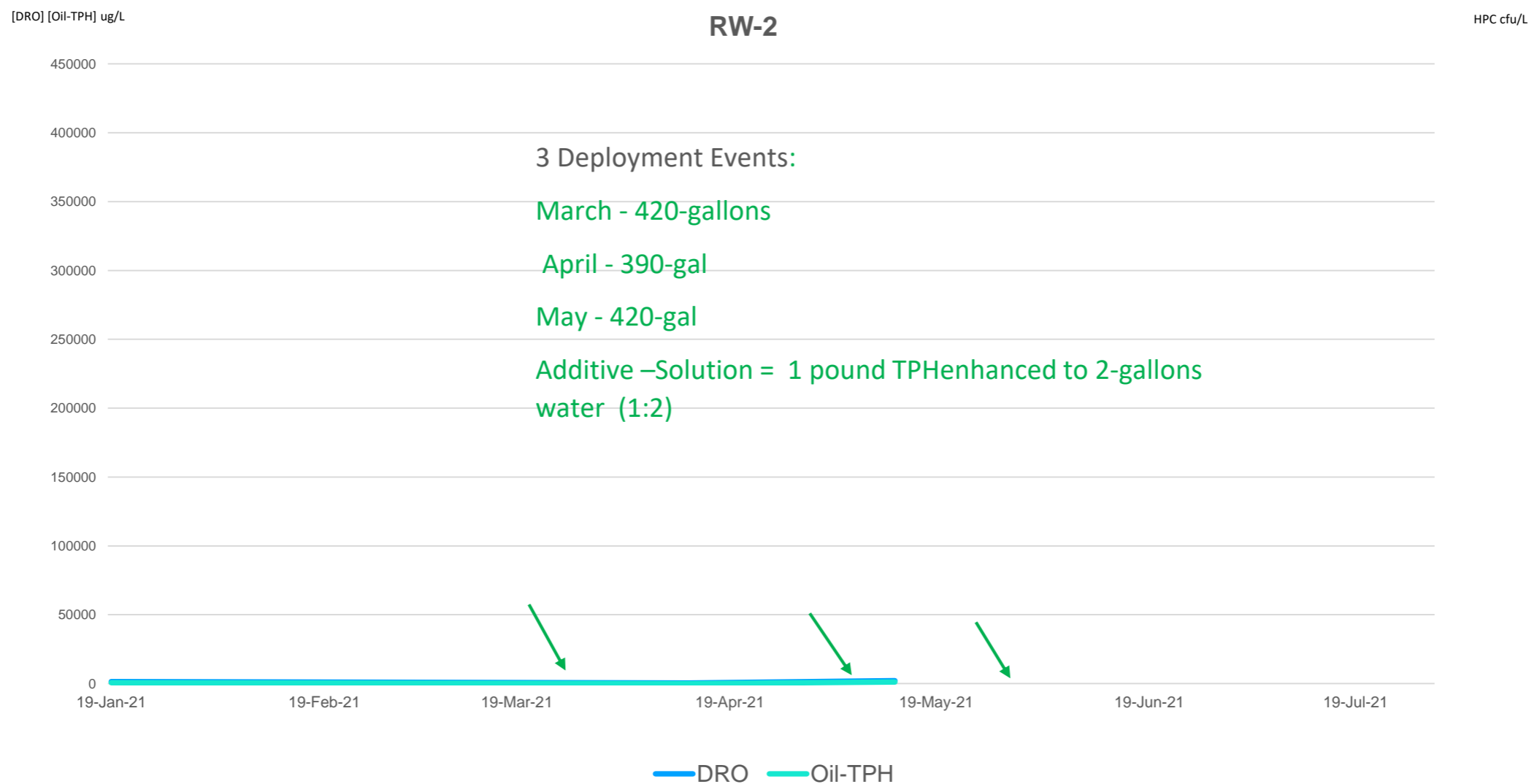
APPLICATIONS:

Petroleum Hydrocarbons(PHCs)
Polychlorinated Aromatics (PAHs)
Naphthalene, MtBE, Creosoles. PCBs



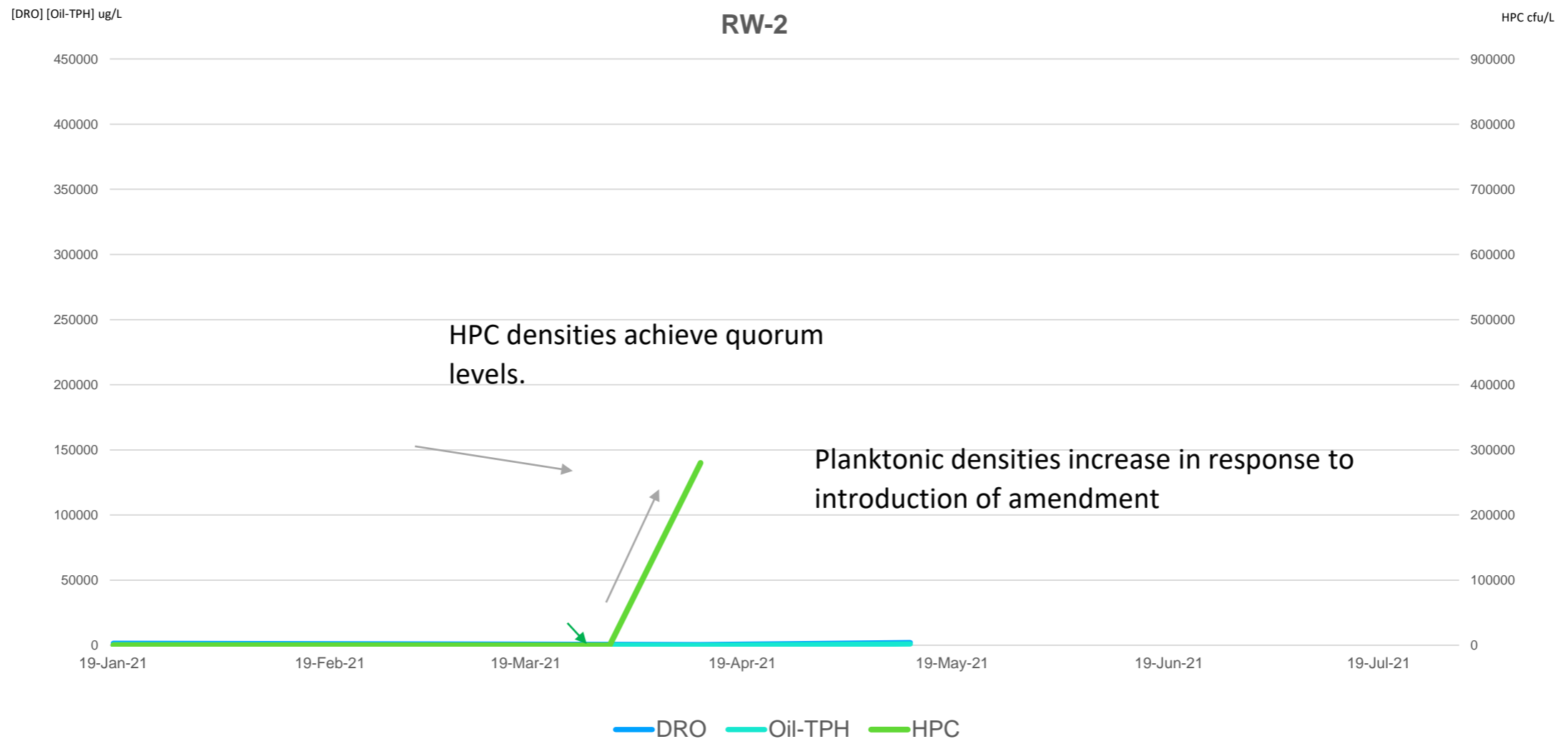
Contaminant Degradation

Biostimulation supported PHC degradation in biofilm.



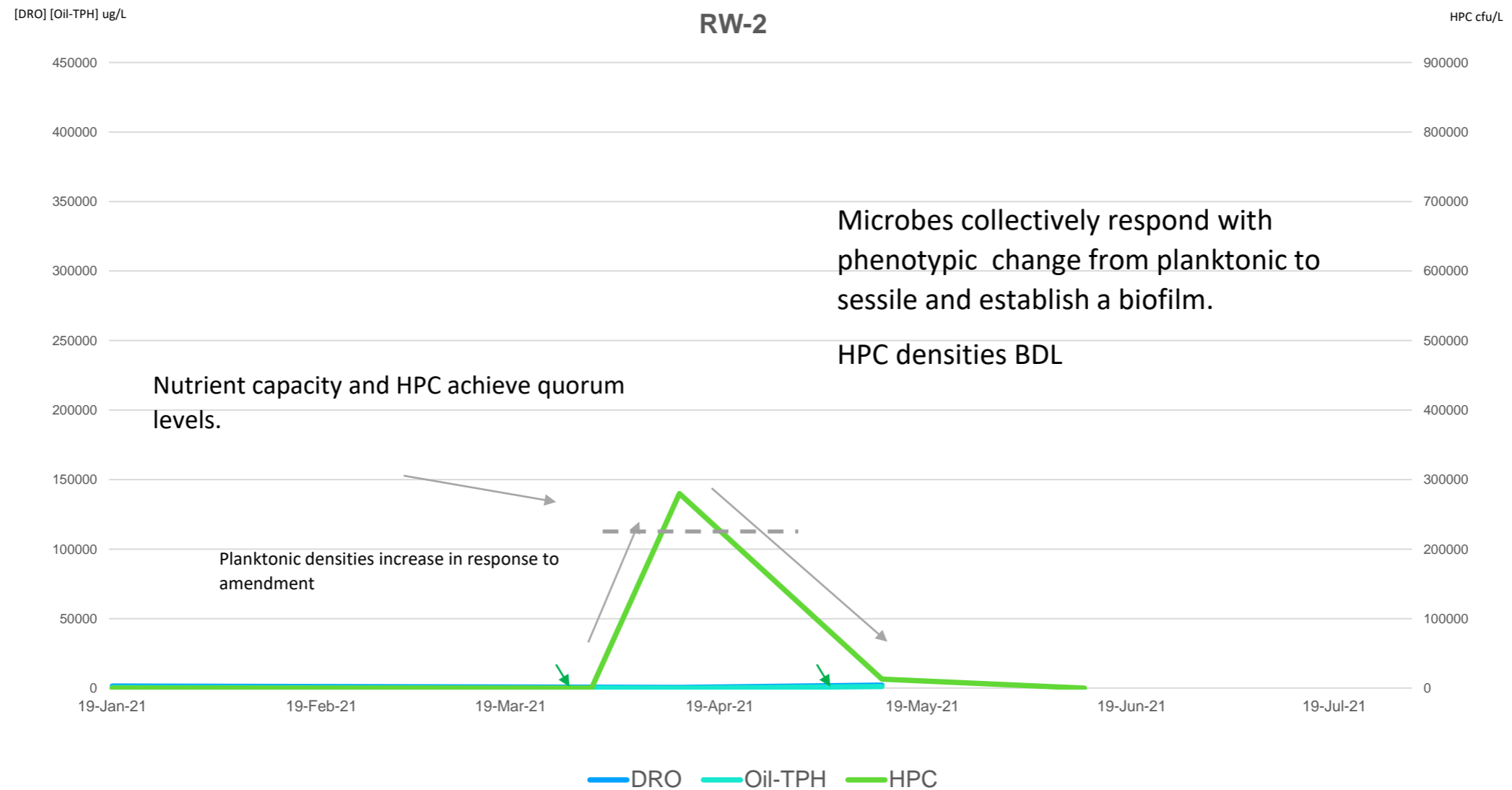
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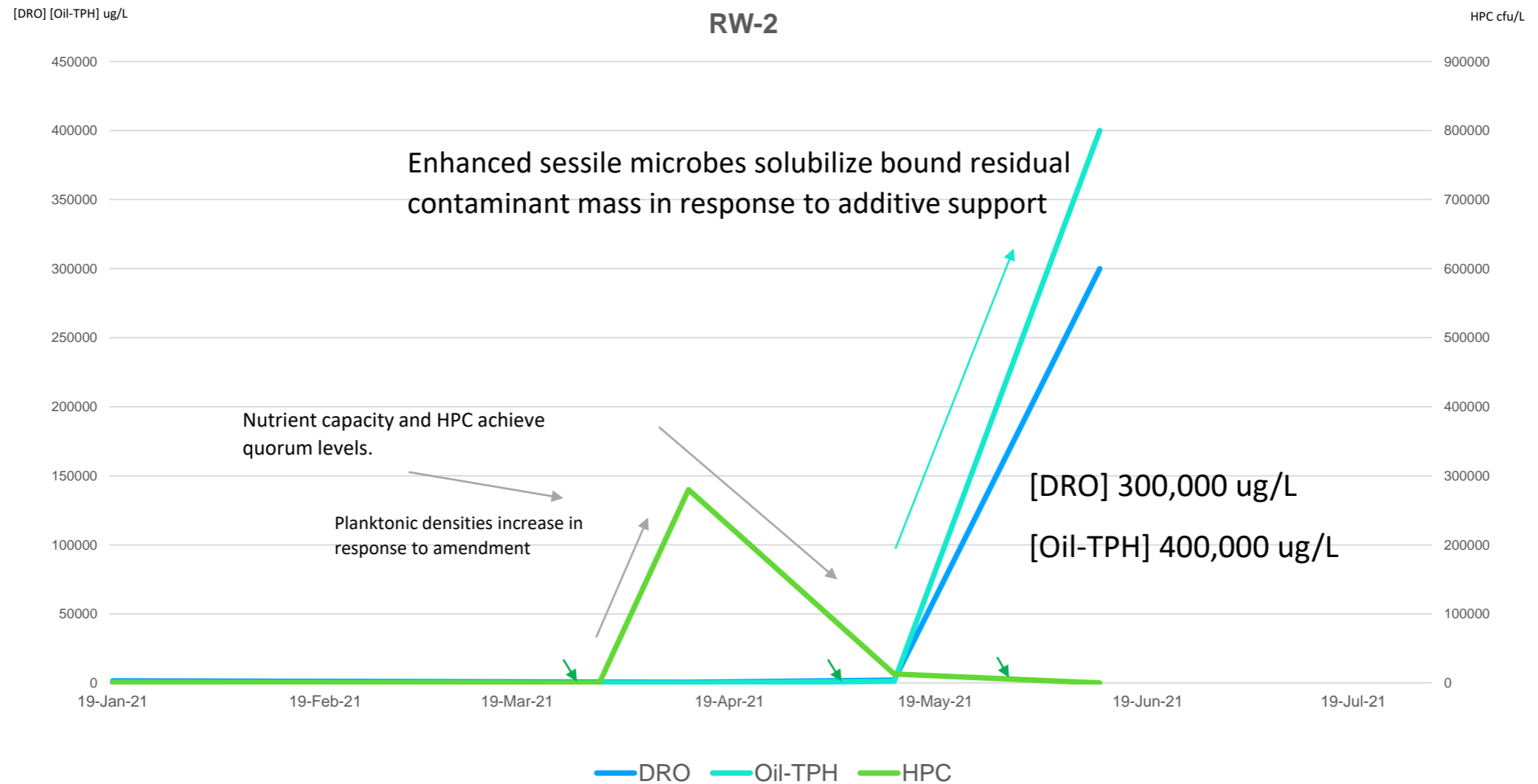
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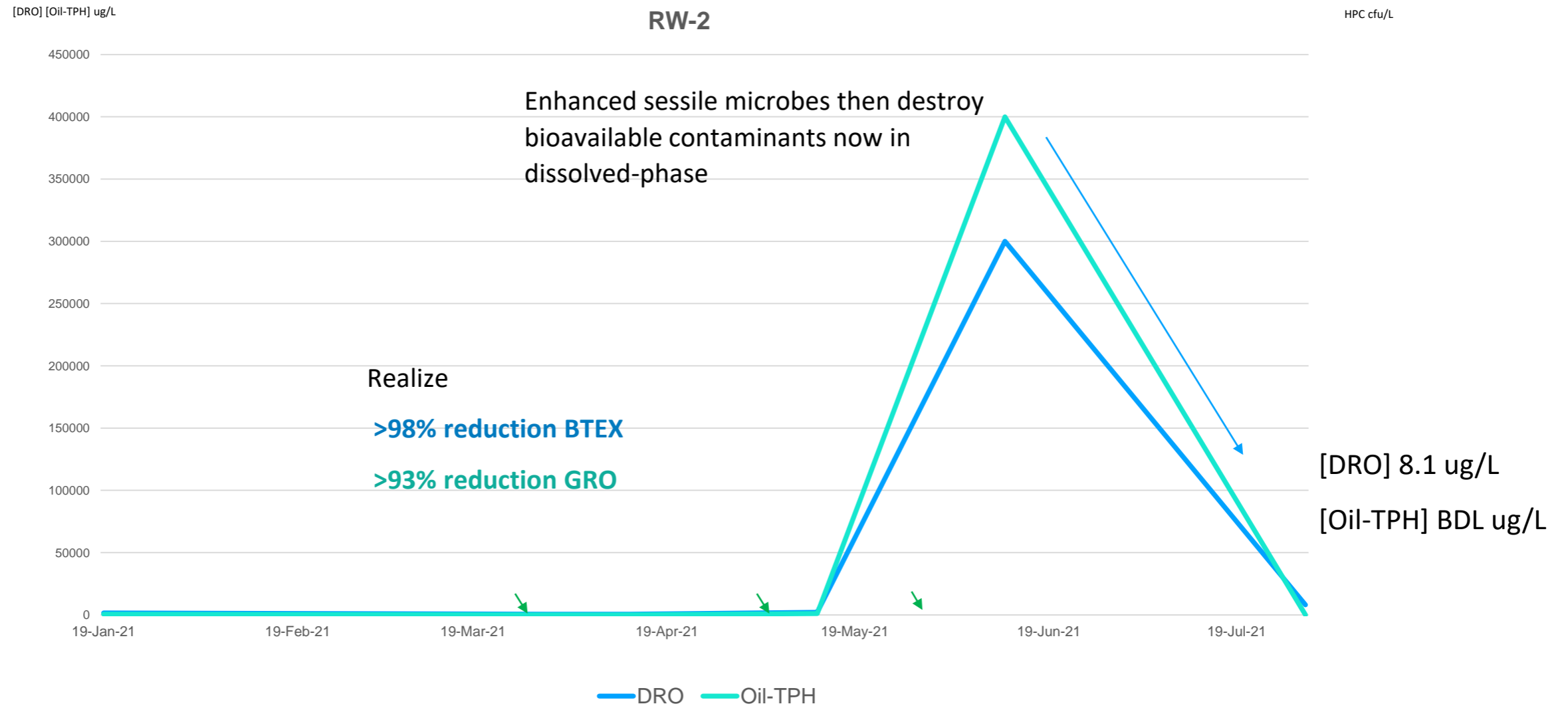
Contaminant Degradation

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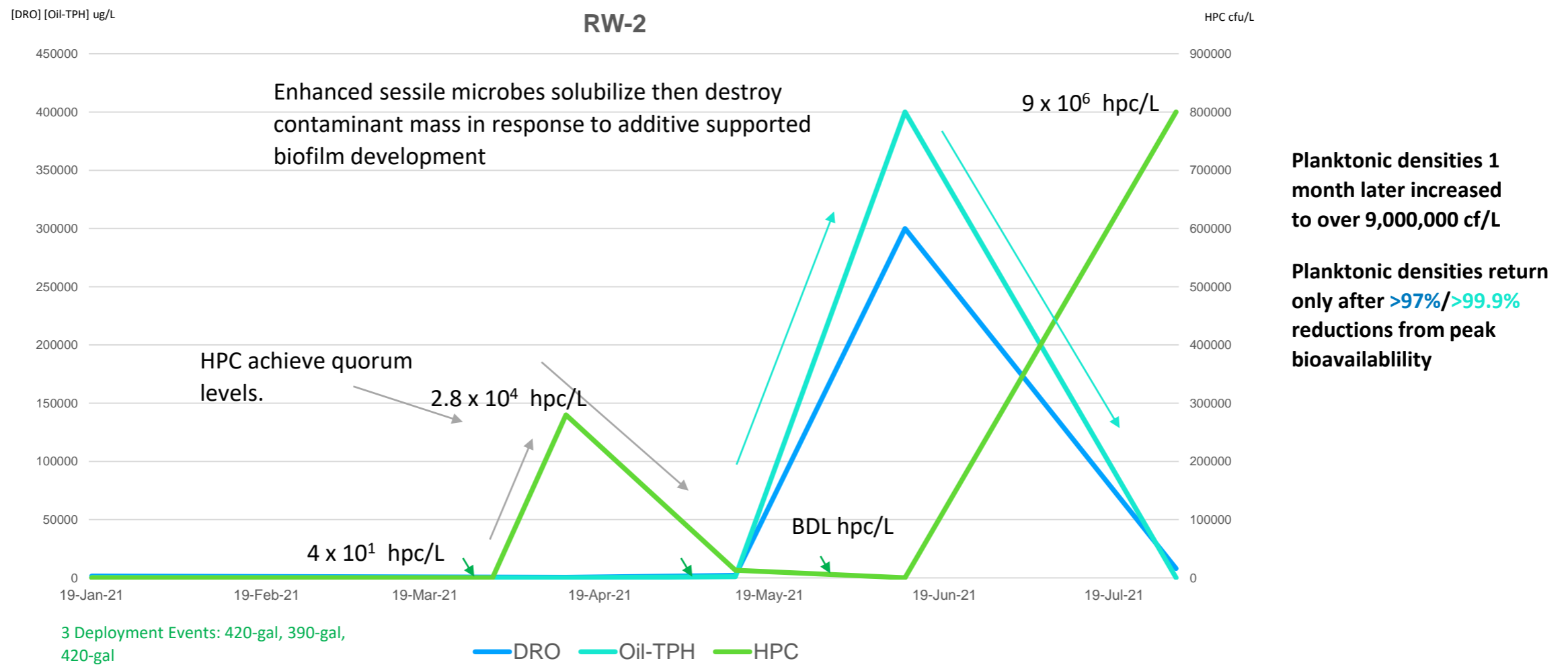
Contaminant Degradation

Biostimulation supported PHC degradation in biofilm.



Contaminant Degradation

Biostimulation supported PHC degradation in biofilm.



Conclusions

TerraStryke biostimulation additives support the subsurface ecosystem and indigenous microbes to expedite:

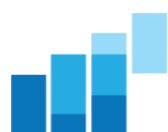
- ✓ LNAPL/DNAPL solubilization.
- ✓ Dissolved-phase contaminant utilization/destruction.
- ✓ The use of organic contaminants as electron donors/acceptors.
- ✓ Sustainable, climate neutral
- ✓ Sequester greenhouse gasses and eliminate aboveground support equipment
- ✓ Simply by letting Nature have it.

**WORKING TOGETHER,
WE SUCCEEDED**

Did you know that prokaryotic bacteria under suitable anaerobic conditions **CHANGE PHENOTYPICALLY, COMMUNICATE/SIGNAL, BUILD, SHARE, AND WORK COLLECTIVELY?**

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BRINGING THE GROUND TO LIFE. TERRASTRYKE.COM

Evaluation Amendments

ERDenhanced™

Supports reducing
conditions for decades after
single injection program

APPLICATIONS:

Dry cleaner, manufacturing, tool-dye

ERDenhanced™

SUSTAINABLE

cVOC remediation with complete
destruction, without rebound,

- with **NO** multiple deployments
- with **NO** secondary contaminants
- with **NO** adverse affects

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Case Study

Burlington, Ontario Site Former Dry Cleaner



Former Dry Cleaner

- [PCE] in saturated soil/groundwater
- Residual source mass in saturated soils



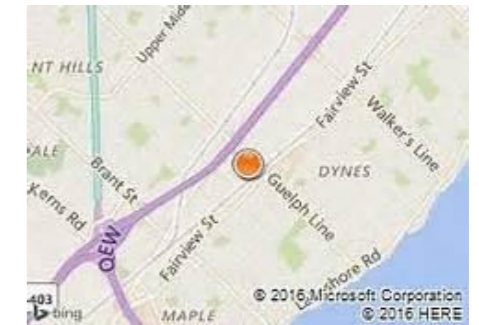
Site Conditions

- Highly weathered Shale with Silty-Sand
- Silt Generally moist
- 1-25ft bgs elevated PID readings



Property Value

- 2011 Appraised Value \$680,000





Excavation – Source Removal

- Excavated 250c.y. contaminated soils
- Infiltration gallery installed w/in footprint
- Clear stone, 6-inch slotted PVC, 6-9ft bgs



Additive Deployment

- Gravity fed 9% additive slurry
- 1,056 lbs to 1,100 gallons chase water
March and again June 2014



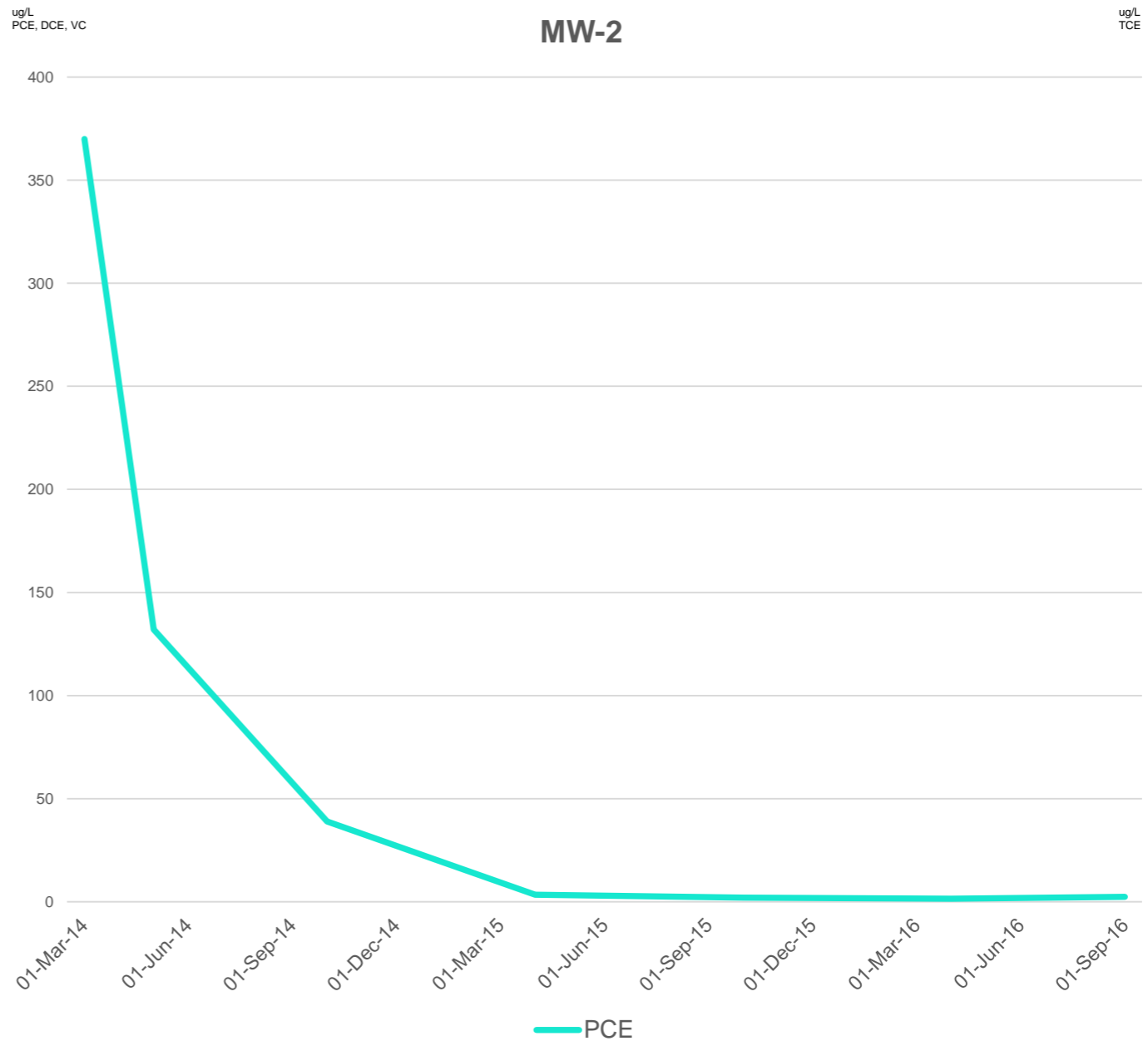
Case Study

Burlington, Ontario Site
Former Dry Cleaner

Results T=2 Years

MW-2 50-60ft downgradient

- 99.4% reduction [PCE]



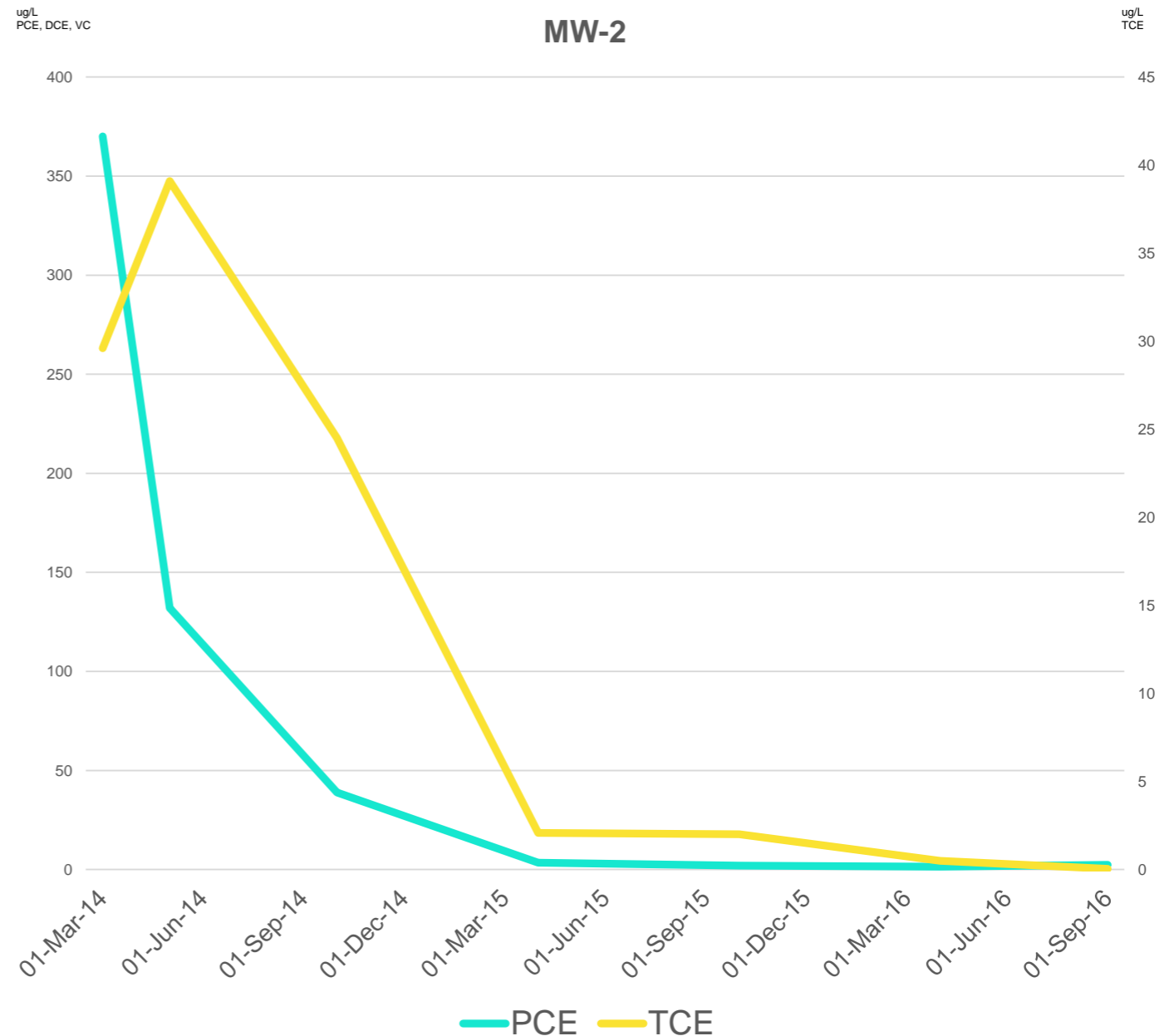
Case Study

Burlington, Ontario Site Former Dry Cleaner

Results T=2 Years

MW-2 50ft downgradient

- 99.4% reduction [PCE]
- After initial 32.1% increase
- 99.9% reduction [TCE] from peak.



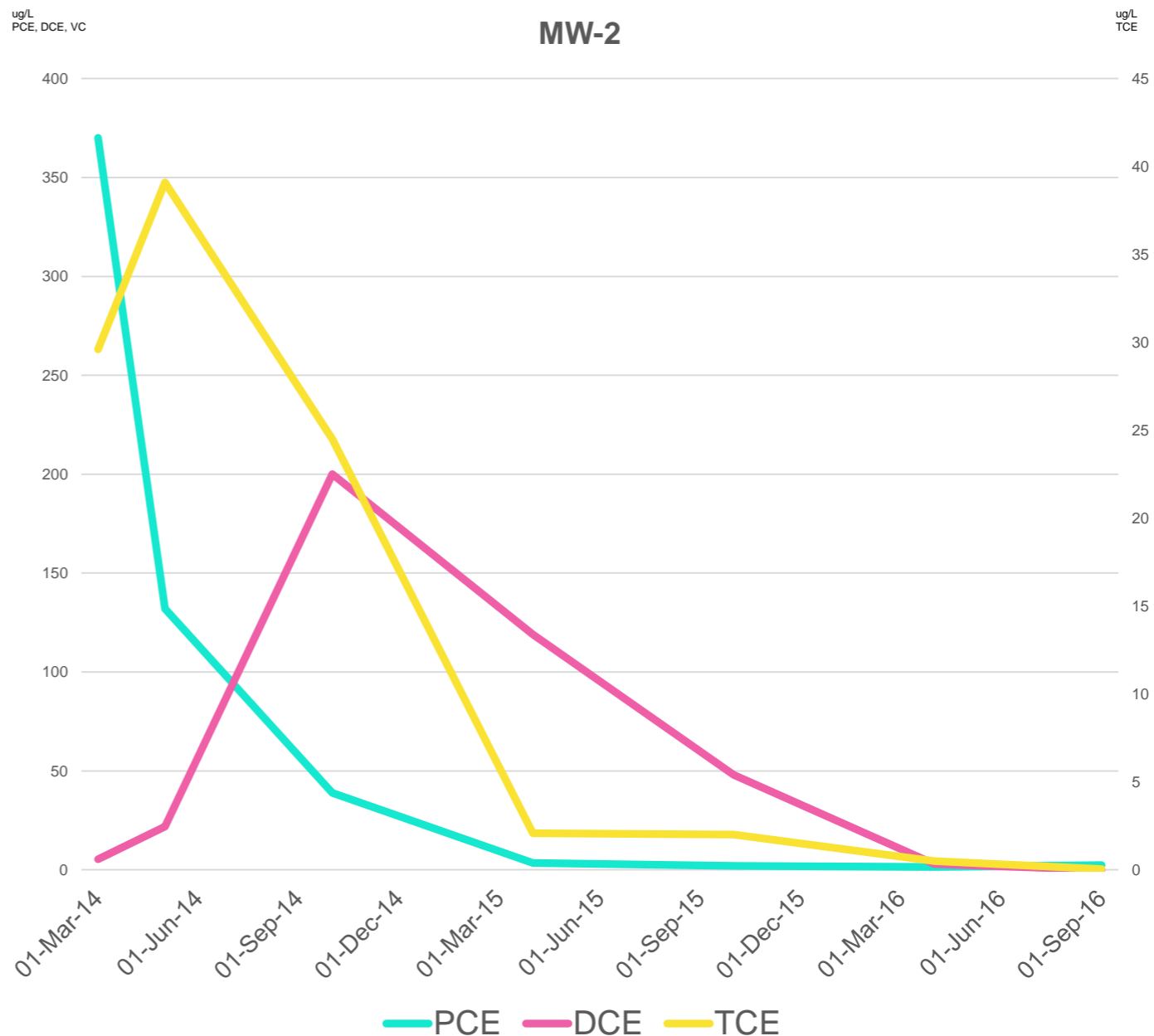
Case Study

Burlington, Ontario Site Former Dry Cleaner

Results T=2 Years

MW-2 50ft downgradient

- 99.4% reduction [PCE]
- 99.9% reduction [TCE]
- After 3,600% increase
- >99.99% reduction [cis-DCE] from peak



Case Study

Burlington, Ontario Site Former Dry Cleaner

Results T=2 Years

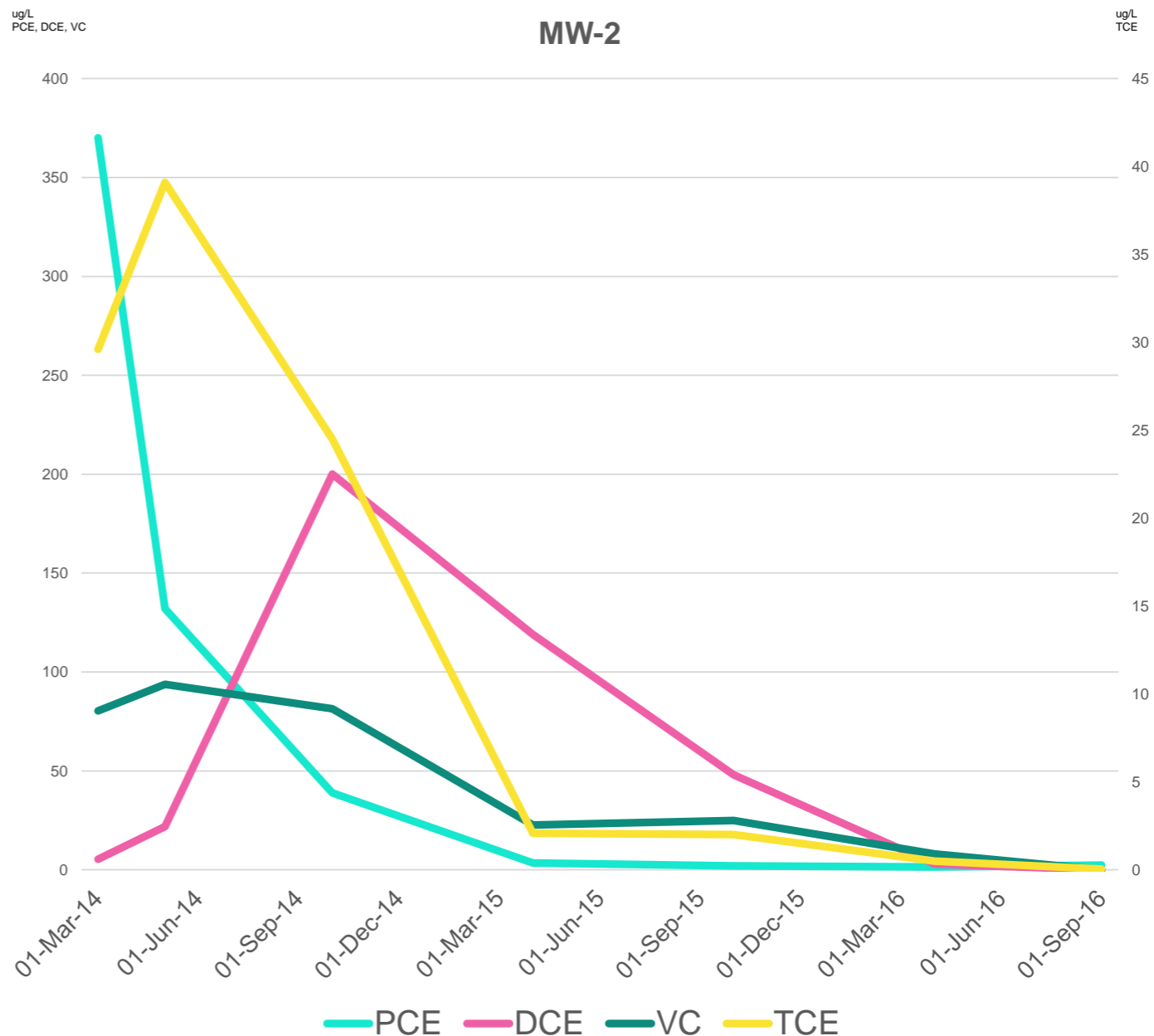
MW-2 50ft downgradient

- 99.4% reduction [PCE]
- 99.9% reduction [TCE]
- ≈100% reduction [cis-DCE]

- 99.9% reduction [VC]
after 16.8%↑

- 99.5% reduction in [cVOCtotal]

- [Ethene] generated throughout
program = complete
biotransformation



**2018 Property
Value Assessed
at MORE THAN
\$2.5
million**



Pump & Treat? Property value \$680,000
P&T ≈ \$750,000-\$1M over 12-15 years
Effective Property Value for 15-years \$0.00



Biostimulation Strategy

Total project Costs

Soil removal/gallery install	\$38,000
Pilot and Full-Scale Additive	\$35,000
Consulting and Analytical	\$150,000
	<hr/>
	\$223,000



During 4th year of remediation Site redeveloped



Property Manager attributes \$1 million of property value increase to remediation strategy



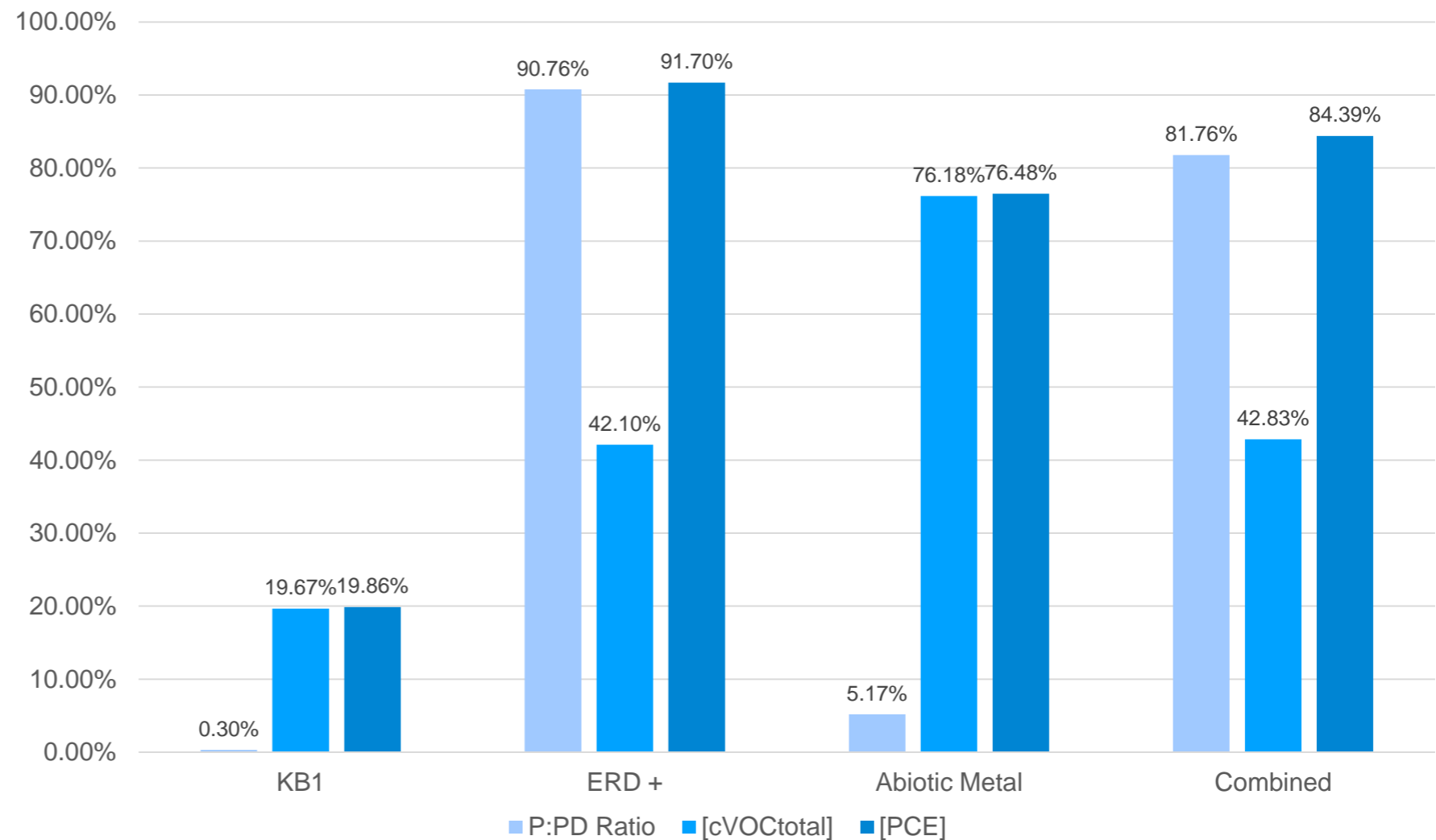
Microcosm Study

Independent Comparative Evaluation

28-day microcosm study

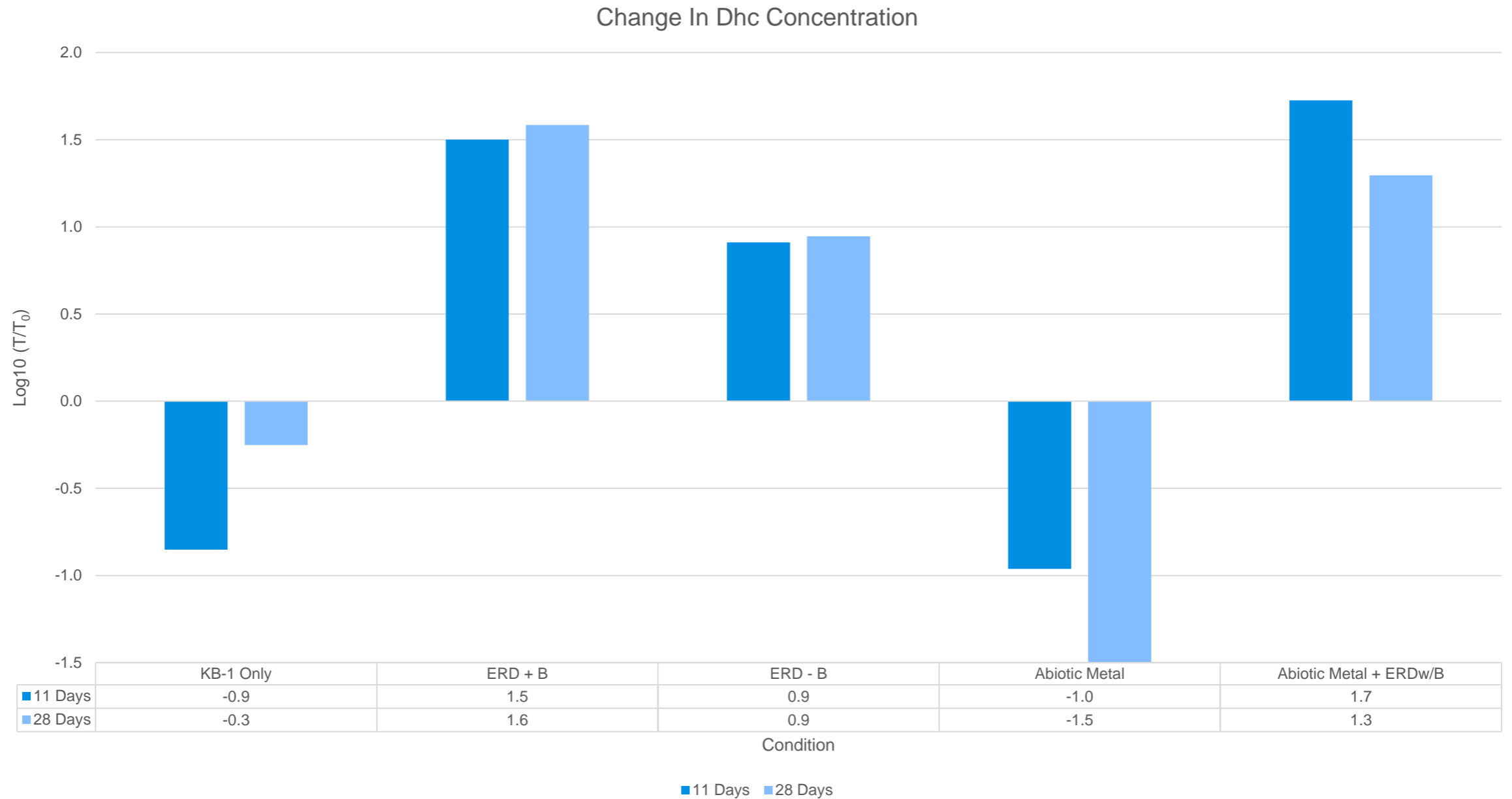
- Baseline [PCE] 50,000 ug/L
- ERD enhanced alone best
- Biology outperformed abiotic

Percent Decreases cVOCs Day 28



Microcosm Study

Independent Comparative Evaluation

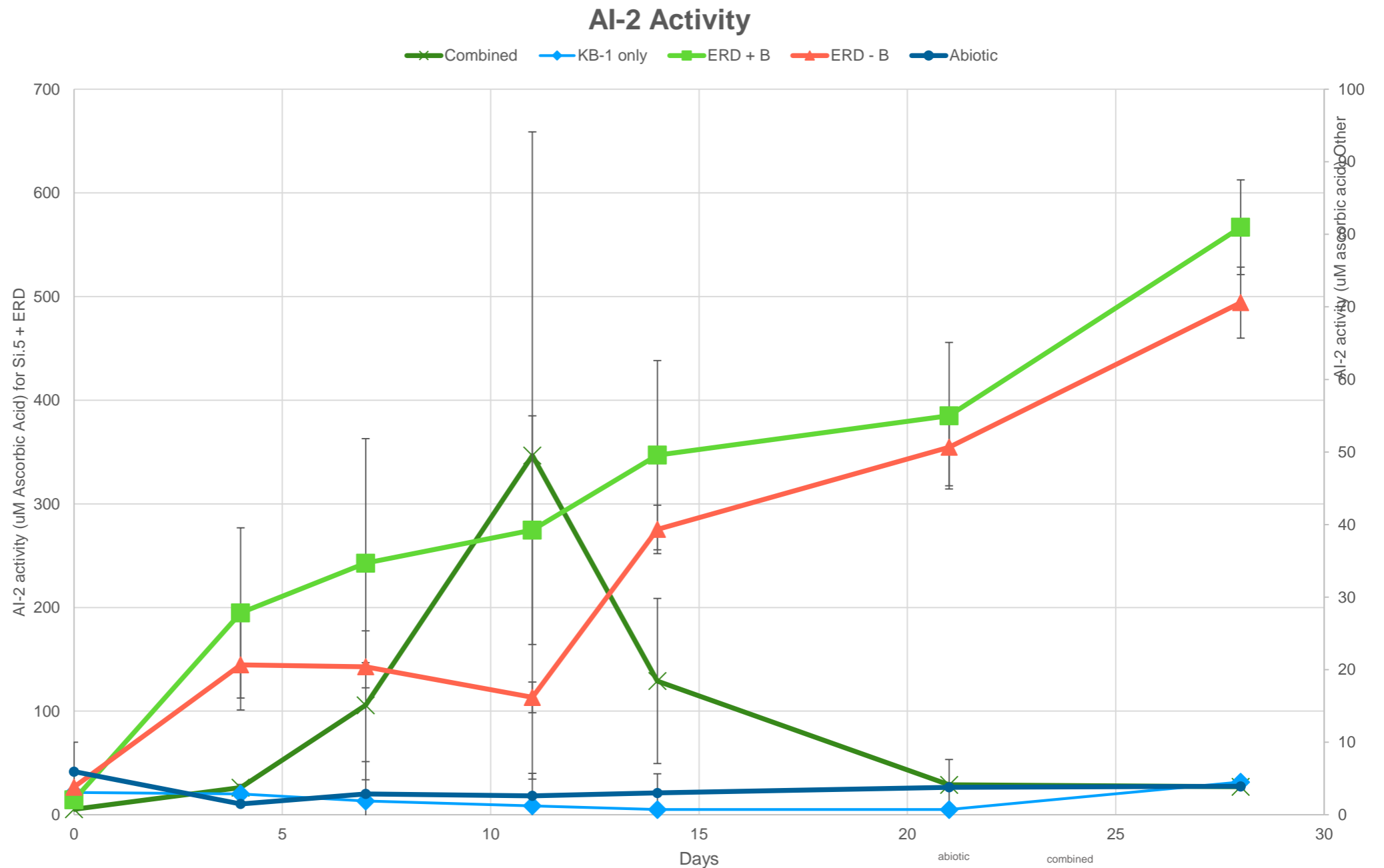


Microcosm Study

Independent Comparative Evaluation

28-day microcosm study

Autoinducer-2 (AI-2) signal realized quorum levels in combined formulae



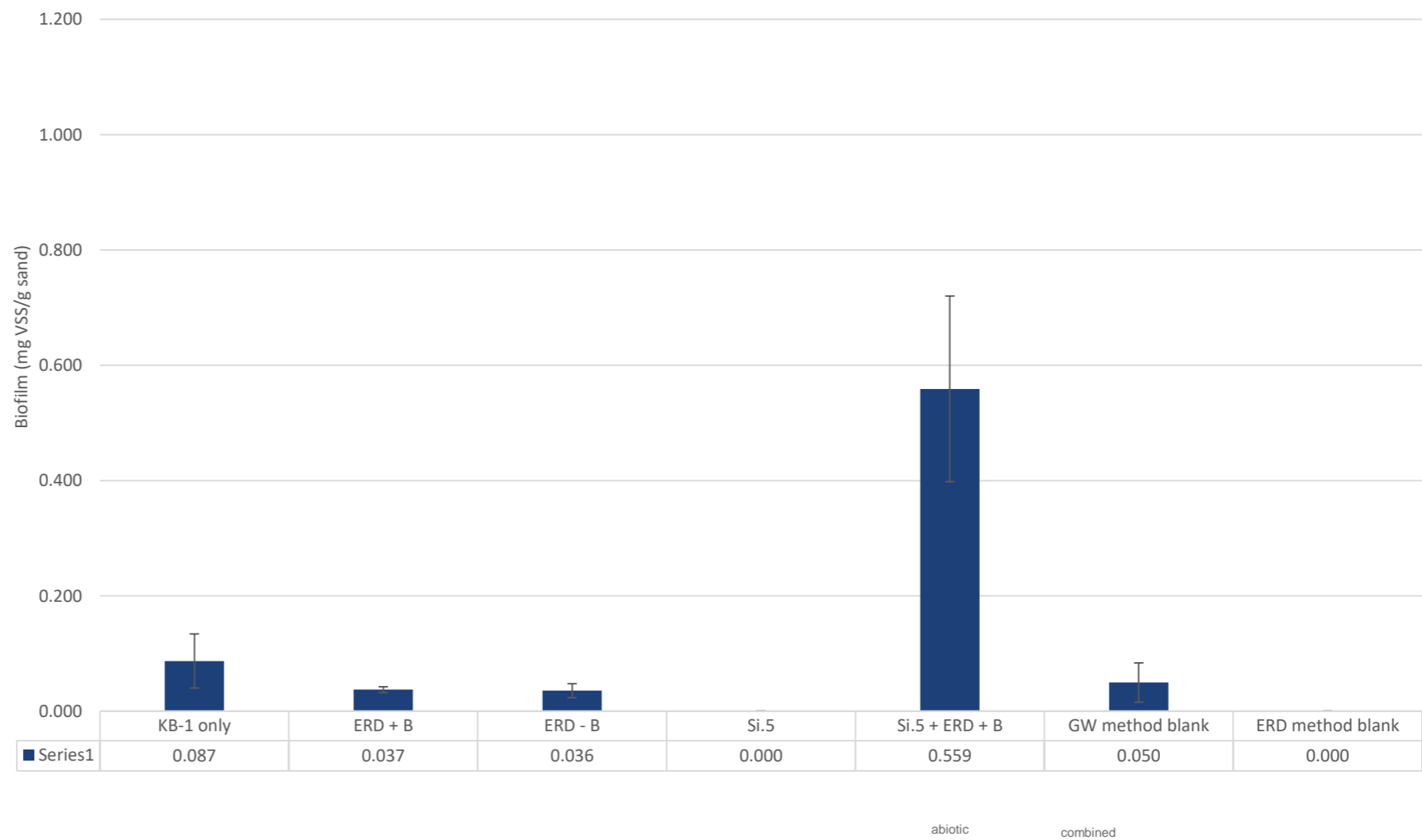
Microcosm Study

Independent Comparative Evaluation

28-day microcosm study

Modified formulae realized greatest biofilm growth

Biofilm Quantity



Field Evaluation Study

Bridgeport Ohio

Former Electronics Manufacturing Facility



Site

- [TCE] in saturated shallow bedrock
- 15-20ft alluvial silty clay/gravelly sand atop bedrock
- Bedrock highly fractured sandstone
- Residual DNAPL in 1⁰/2⁰ pore space of bedrock



Concern

- [TCE] 55-550 milligrams per Litre (mg/L)
- Minimal daughter product present
- Current P&T System manages plume migration



Goal

- Owner desires sustainable low-impact, low-cost strategy to target the destruction of dissolved phase and residual source mass contaminants.



Field Evaluation Study

Bridgeport Ohio

Former Electronics Manufacturing Facility



Strategy

- On-Site proof-of-concept evaluation
- Performed under actual biogeochemical conditions
- Compared ERDenhanced standard formulation
- to modified version containing a minimal % of electron generating metal



Process

- Amend monitoring/test wells using Passive Release Sock (PRS)
- One with original, one with modified ERDenhanced
- Monitor/sample test wells over 12-month evaluation

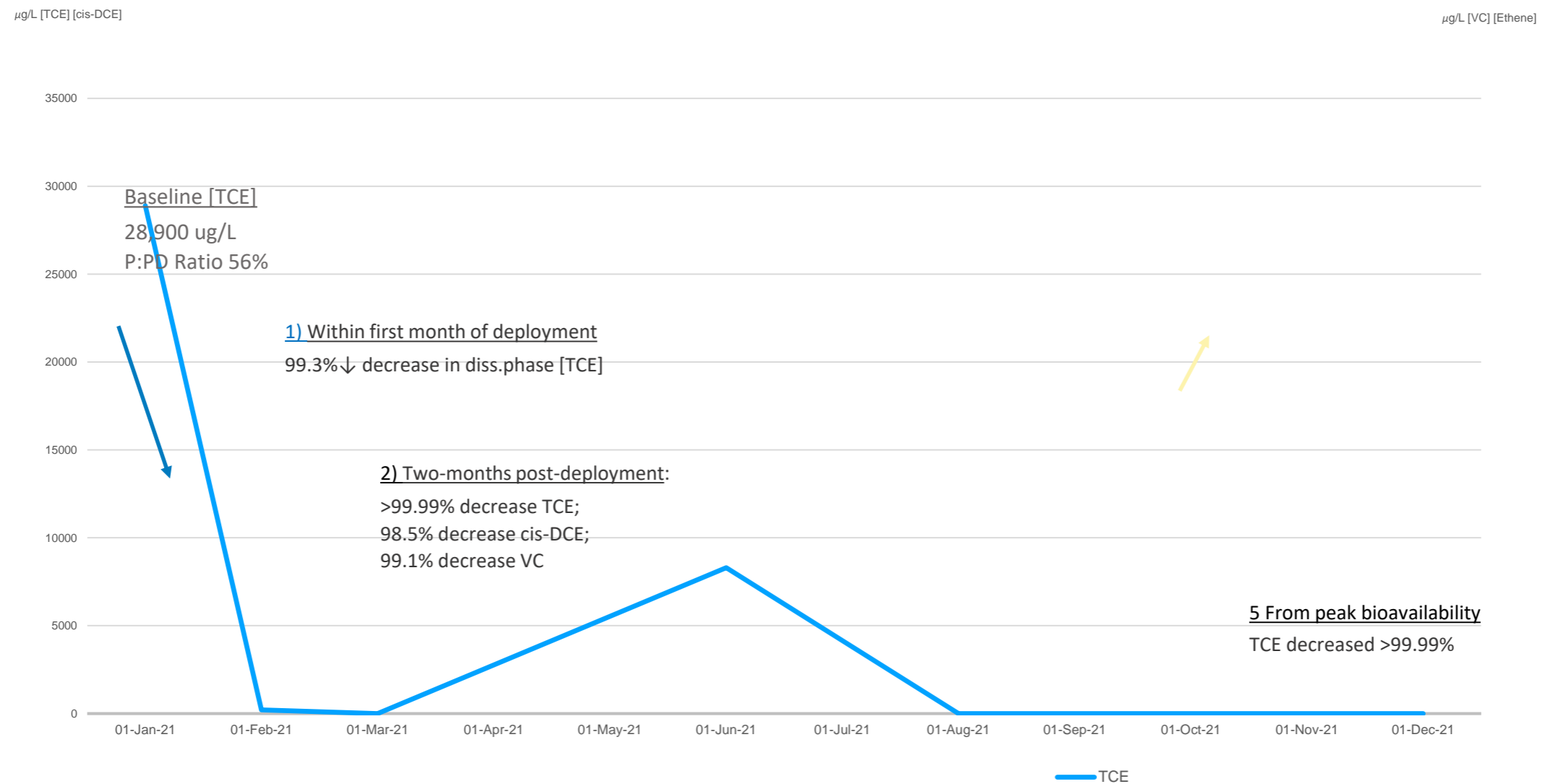


Goal

- Realize increased densities of indigenous microbials
- Expedited residual mass solubilization
- Enhanced and complete dissolved phase cVOC destruction



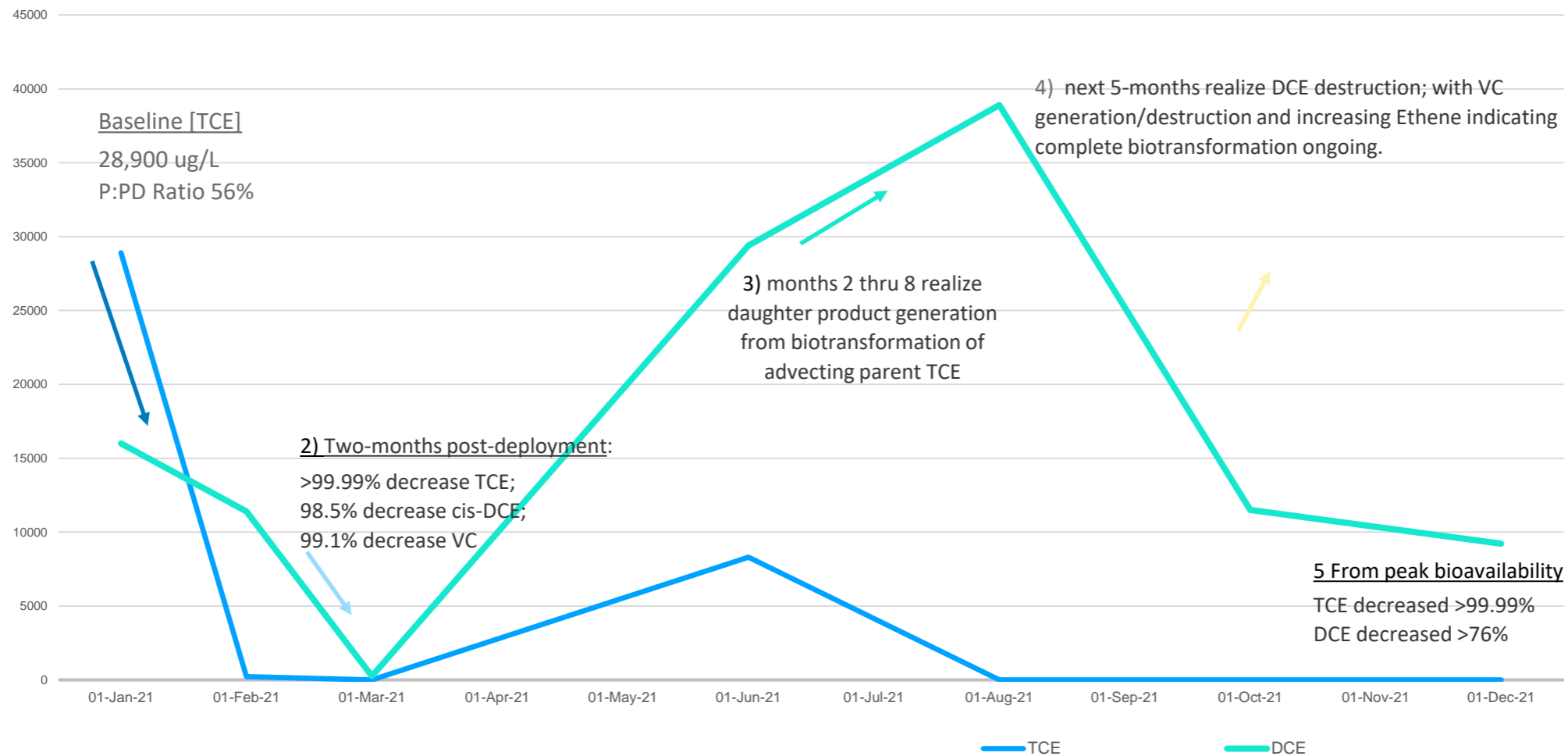
ERDENHANCED MW-23A 12-month evaluation



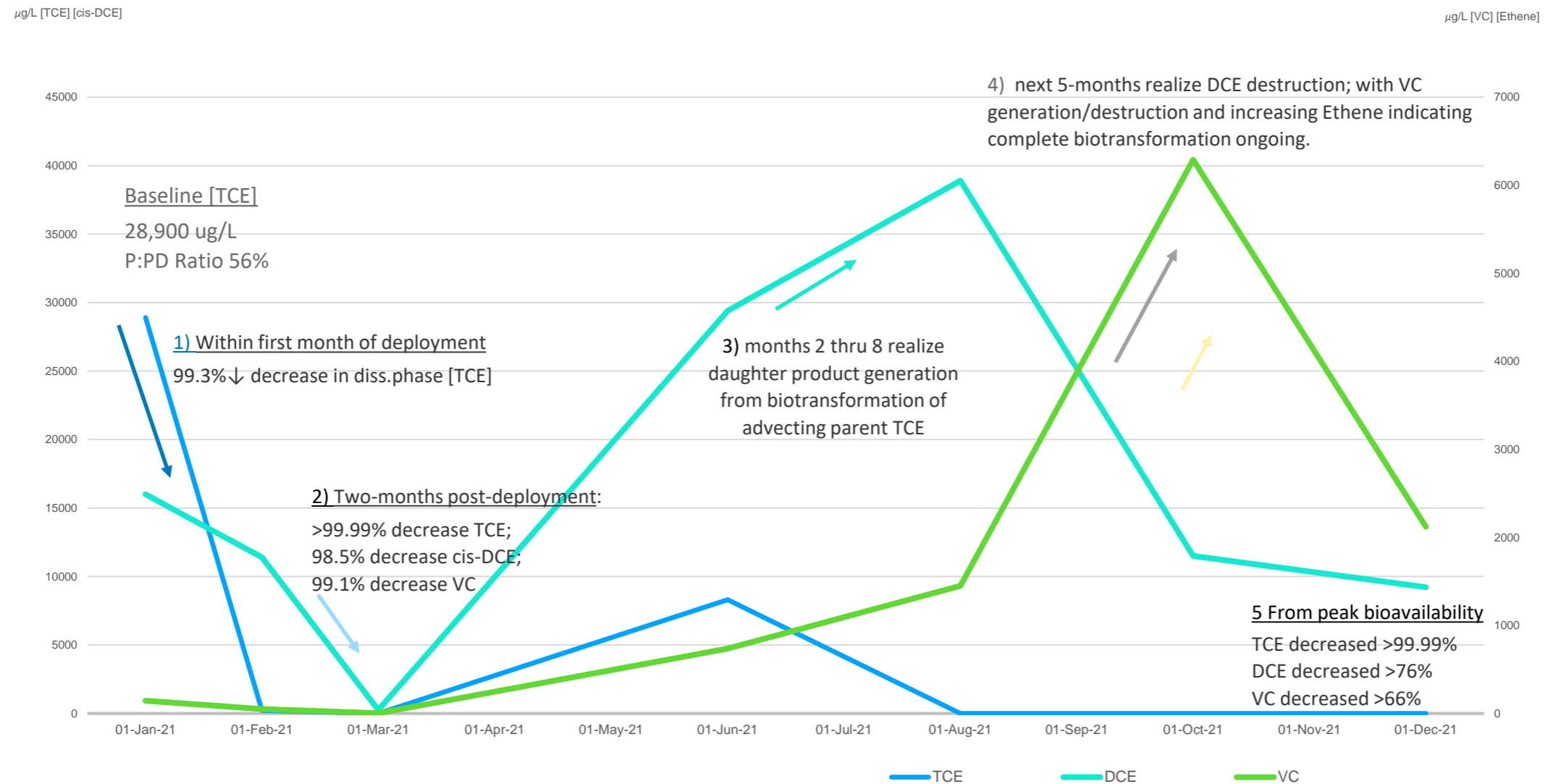
ERDENHANCED MW-23A 12-month evaluation

µg/L [TCE] [cis-DCE]

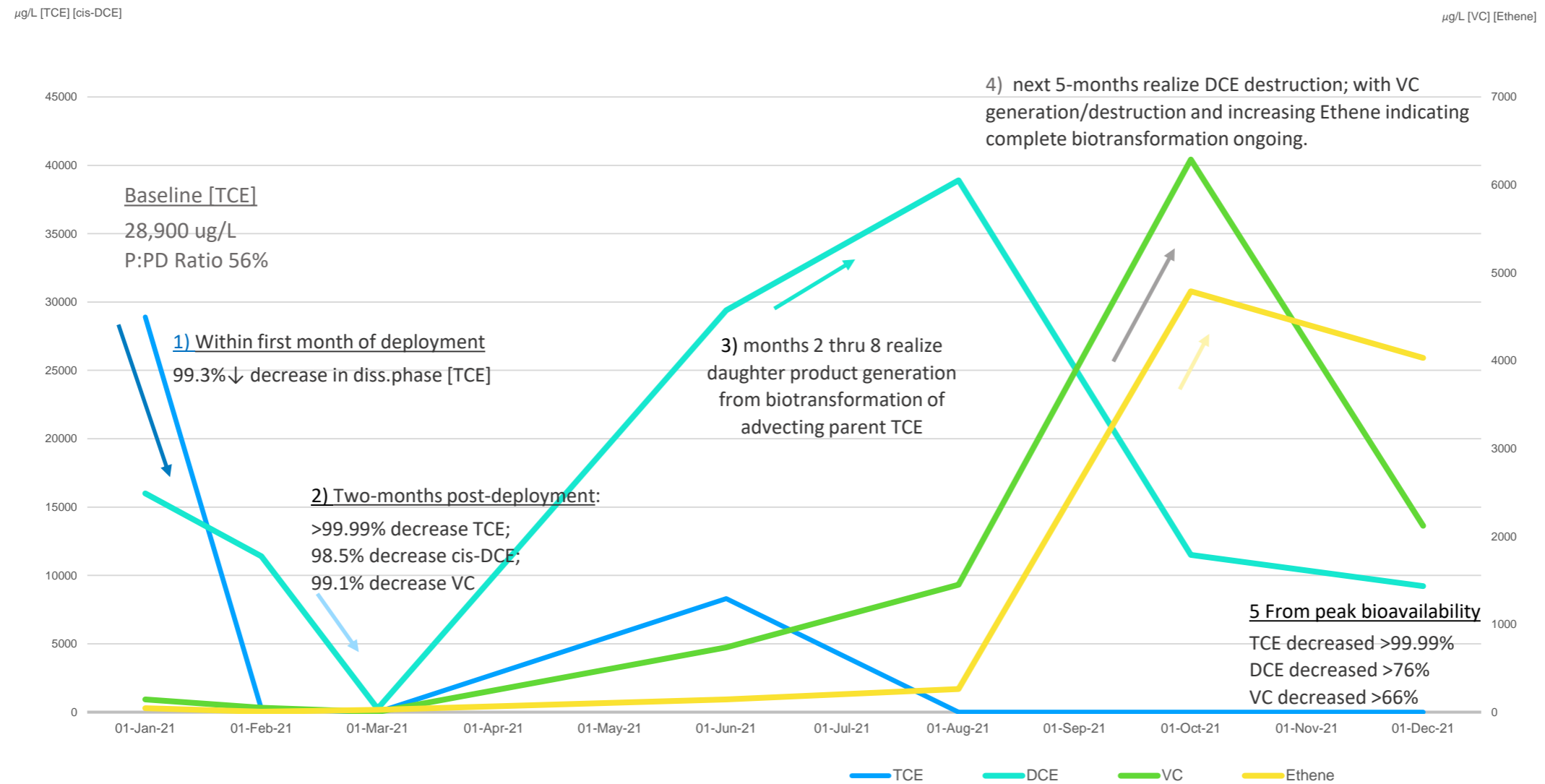
µg/L [VC] [Ethene]



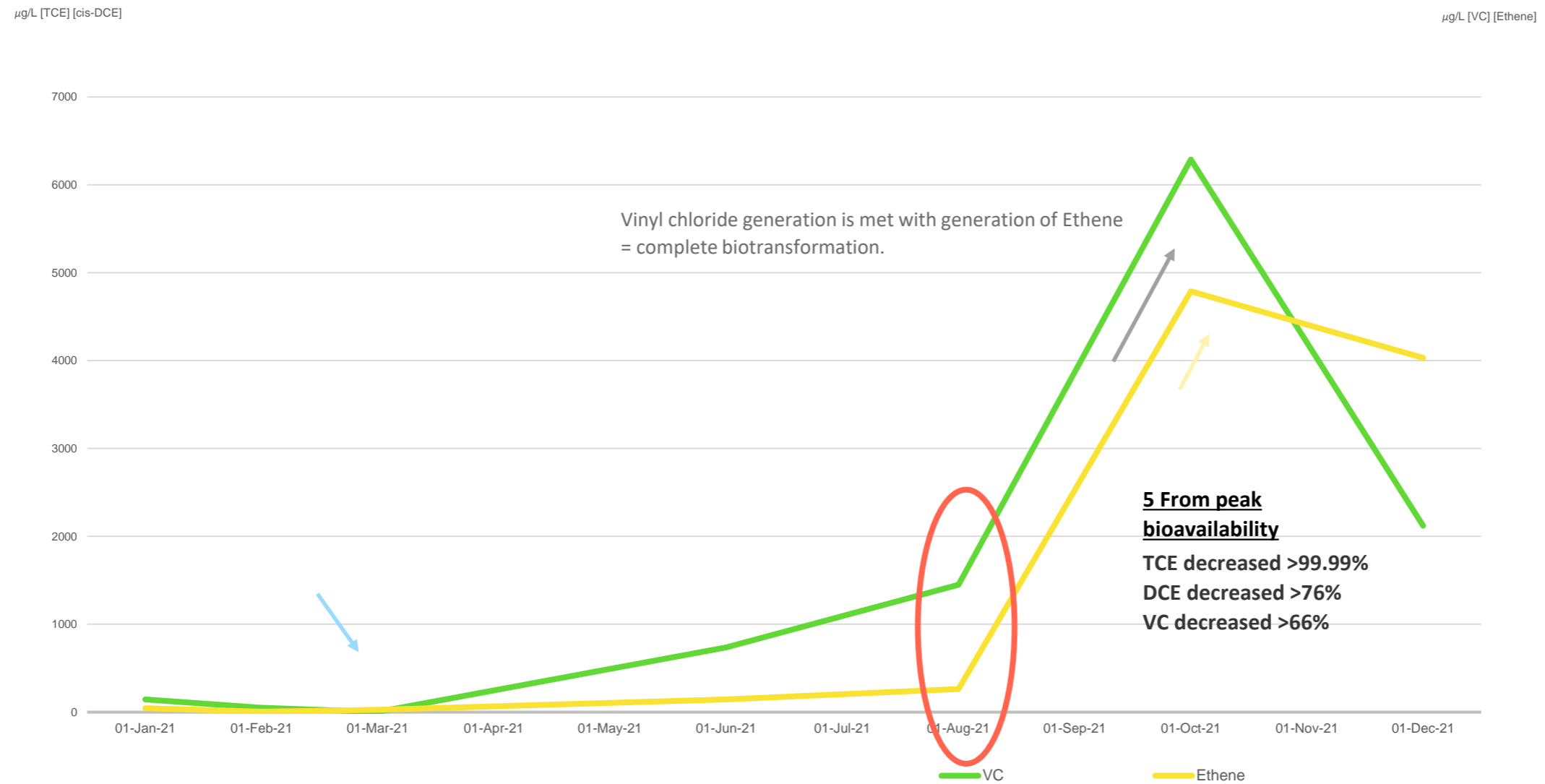
ERDENHANCED MW-23A 12-month evaluation



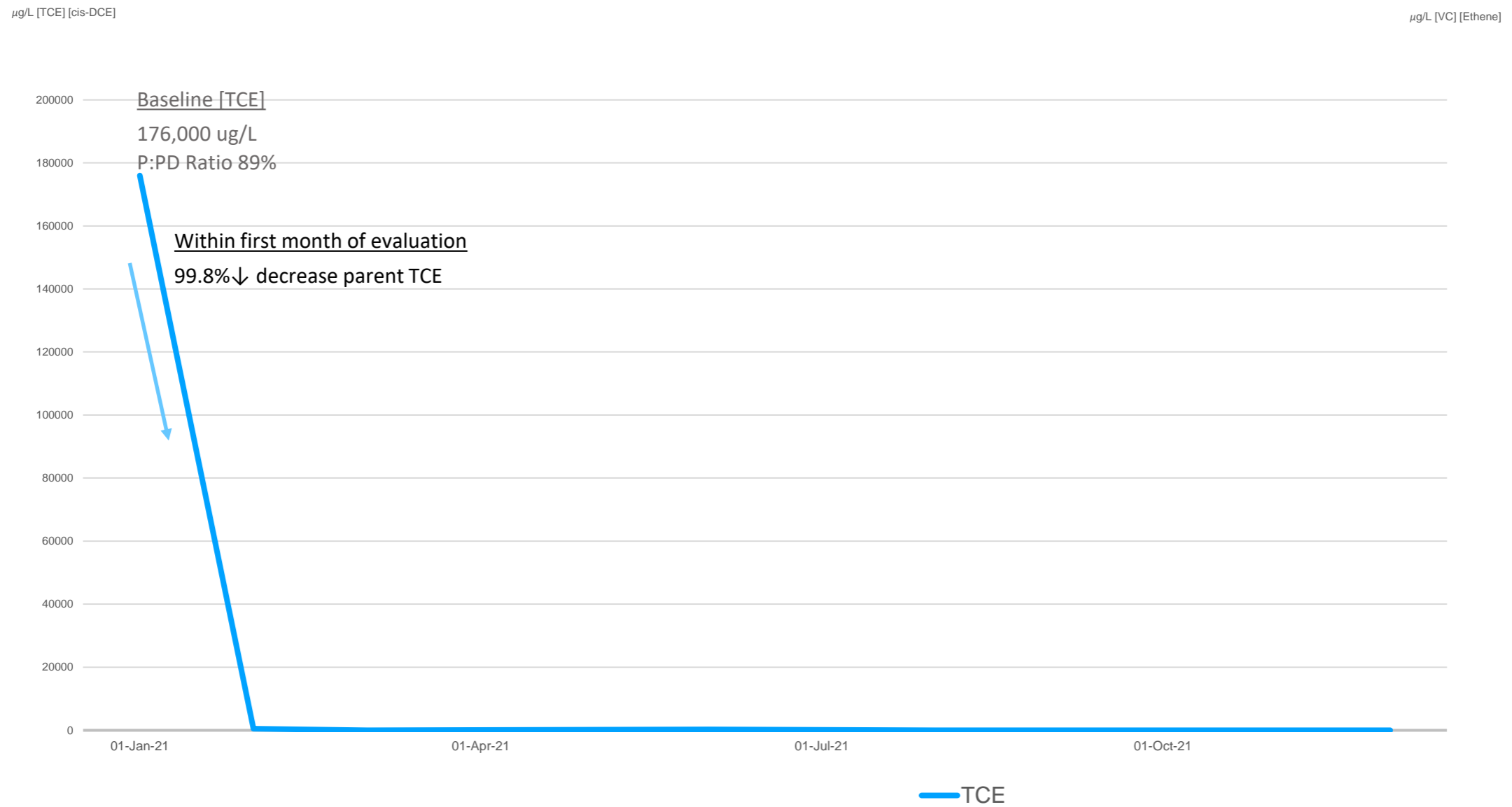
ERDENHANCED MW-23A 12-month evaluation



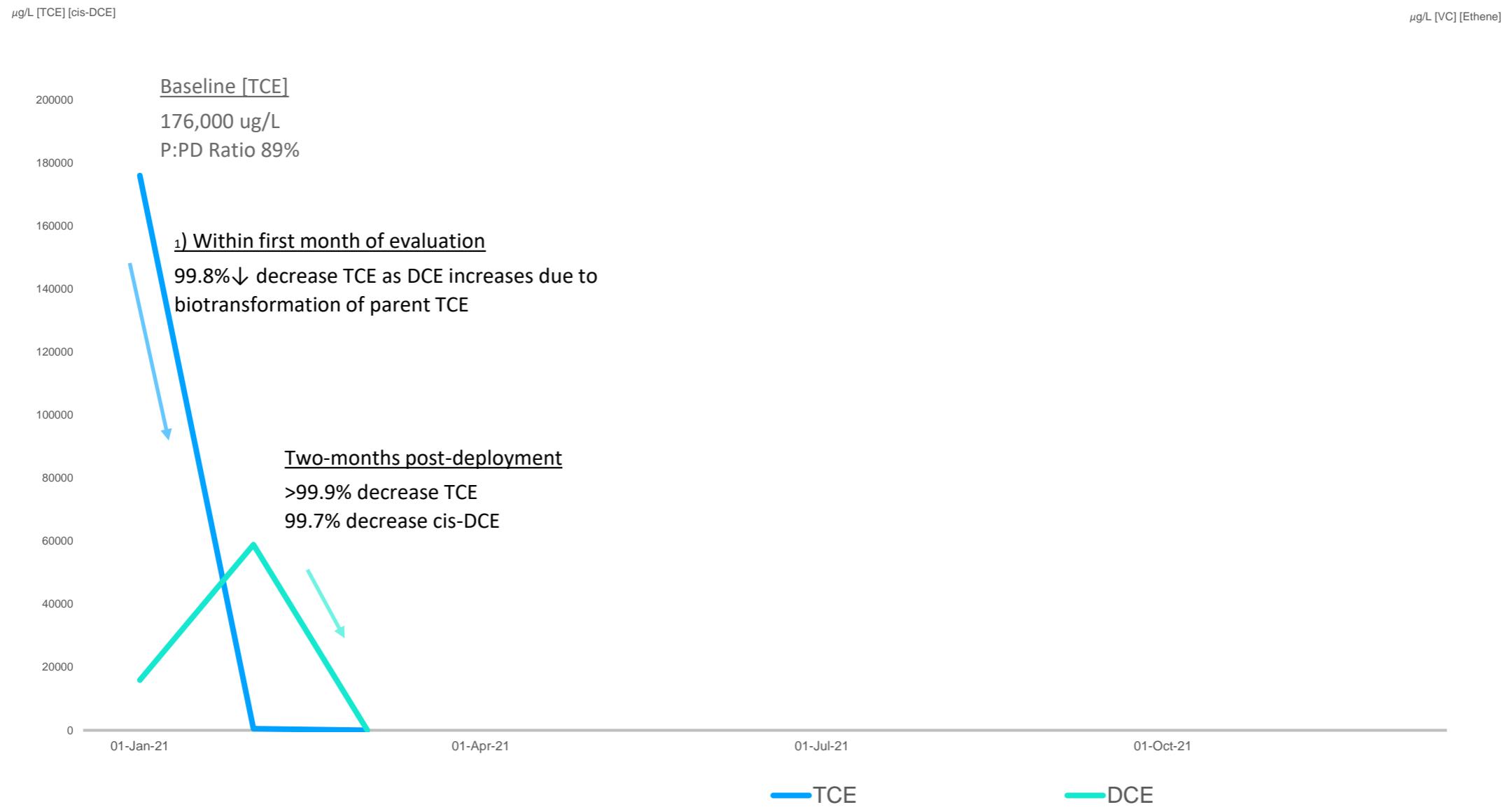
ERDENHANCED MW-23A 12-month evaluation



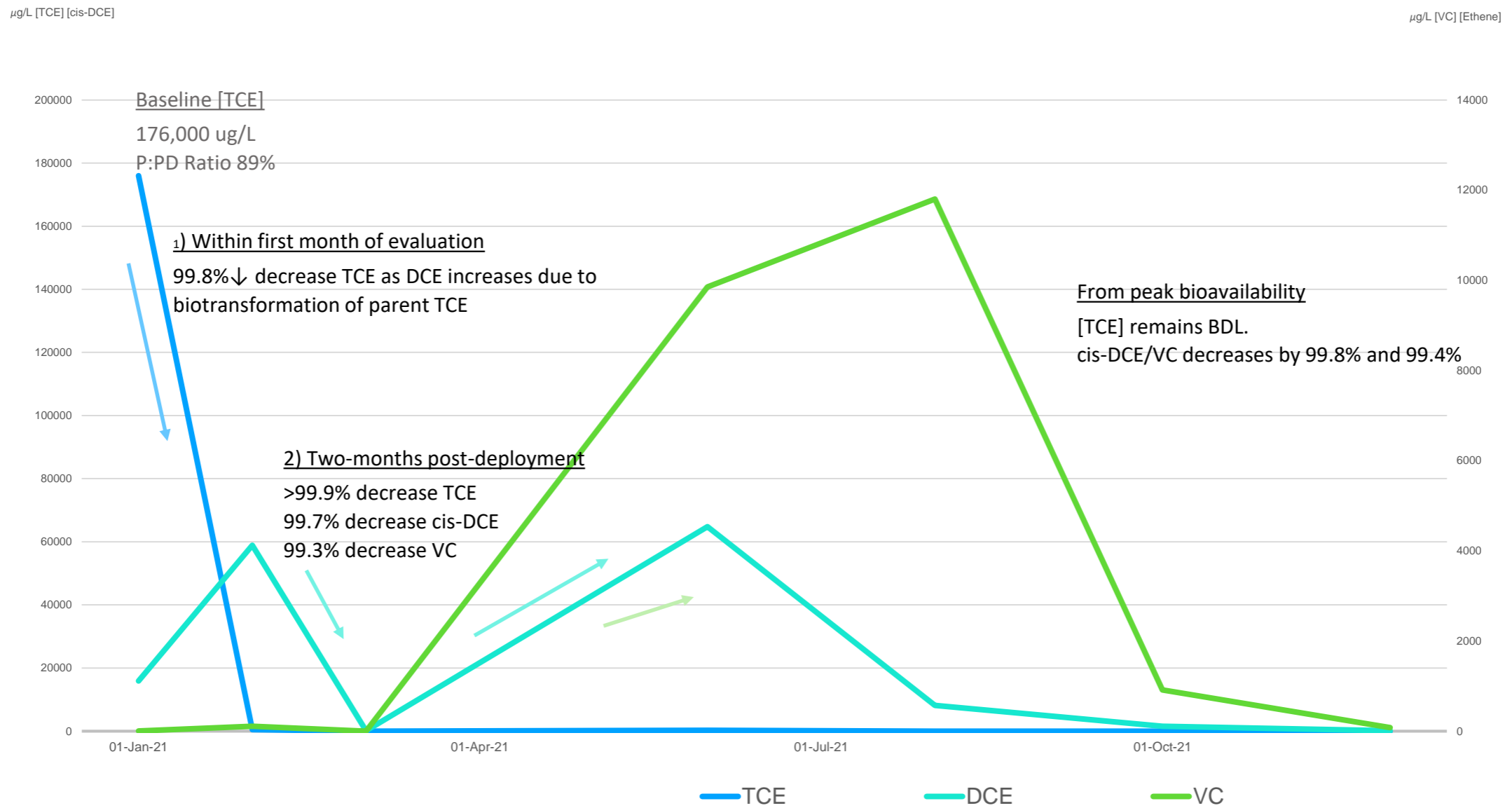
ERDENHANCED w/ ZVI MW-24A



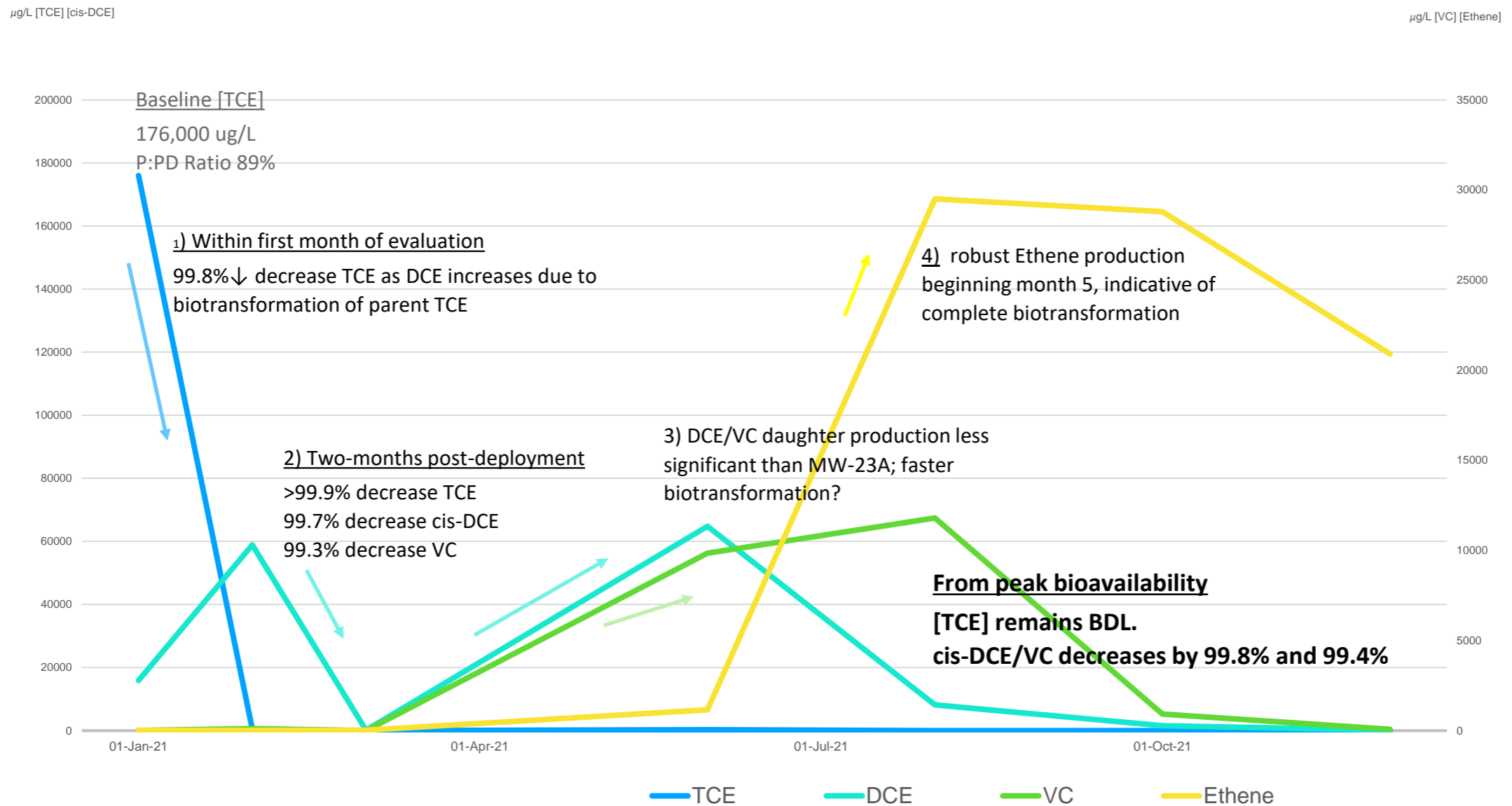
ERDENHANCED W/ ZVI MW-24A



ERDENHANCED W/ ZVI MW-24A



Modified ERDENHANCED MW-24A



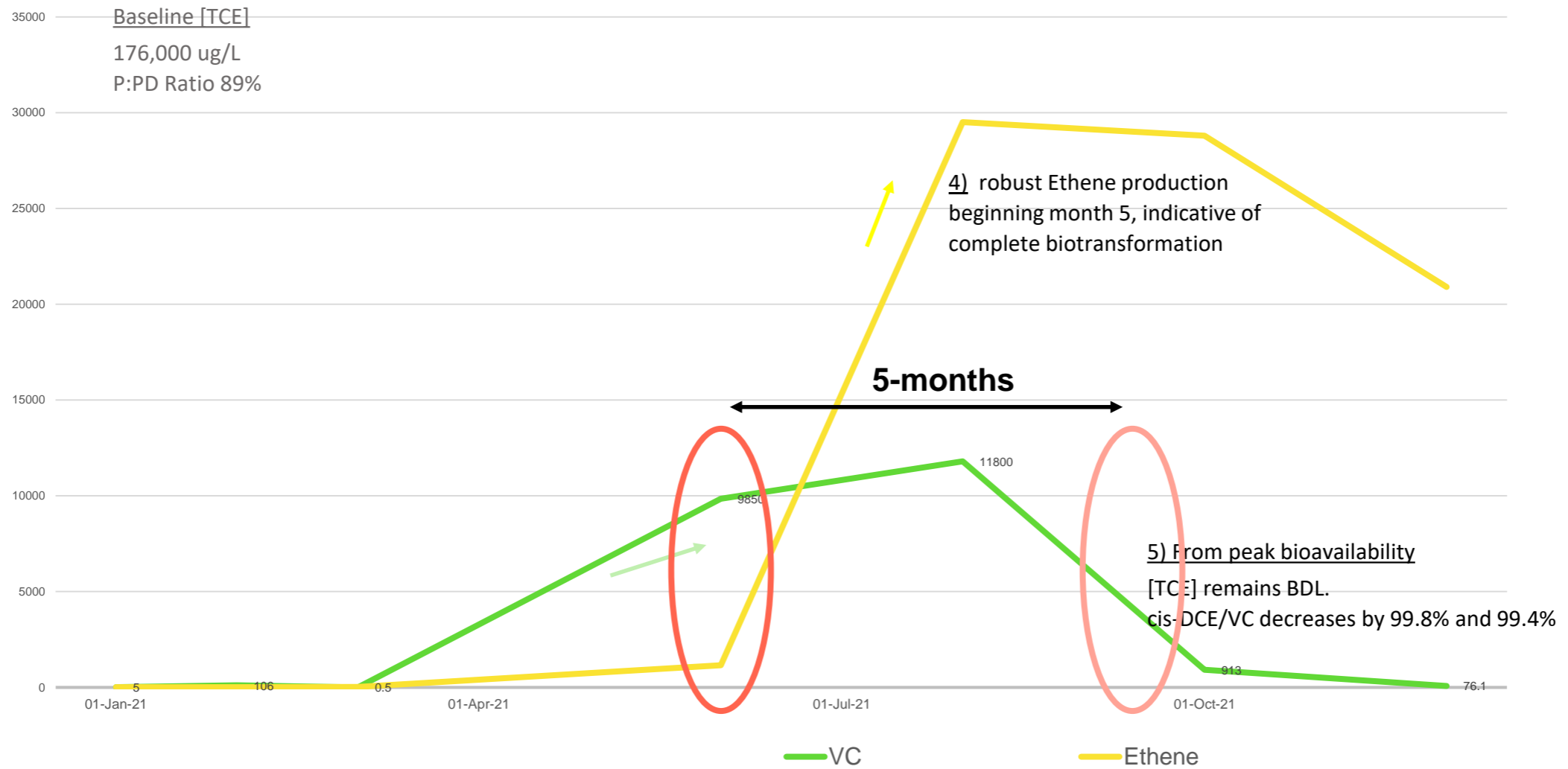
Field Study

On-Site Proof-of-Concept

ERDENHANCED W/ ZVI MW-24A

µg/L [TCE] [cis-DCE]

µg/L [VC] [Ethene]



Field Evaluation Study

Summary

Former Electronics Manufacturing Facility



ERDenhanced

- Achieves robust and complete DNAPL dehalorespiration
- Without 'cis-stall', sustainably for decades after single deployment



Modified Formulation

- Minimal additional of electron generating metal
- Catalyzes biology
- Expedites diss.phase contaminant reductions; while,
- Realizing complete and long-term dehalorespiration of DNAPL and diss.phase contaminants




Conclusions

TerraStryke biostimulation additives support the subsurface ecosystem and microbes to expedite:

- ✓ LNAPL/DNAPL solubilization.
- ✓ Dissolved-phase contaminant utilization/destruction.
- ✓ The use of organic contaminants as electron donors/acceptors.
- ✓ Achieve sustainable remediation without above ground equipment costs/permitting.
- ✓ Sequester Greenhouse Gasses.
- ✓ Realize Site Compliance with less impacts, less costs simply by letting Nature have it.

**WORKING TOGETHER,
WE SUCCEED**

Did you know that prokaryotic bacteria under suitable anaerobic conditions **CHANGE PHENOTYPICALLY, COMMUNICATE/SIGNAL, BUILD, SHARE, AND WORK COLLECTIVELY?**

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STRYKE** #bioremediation4point0

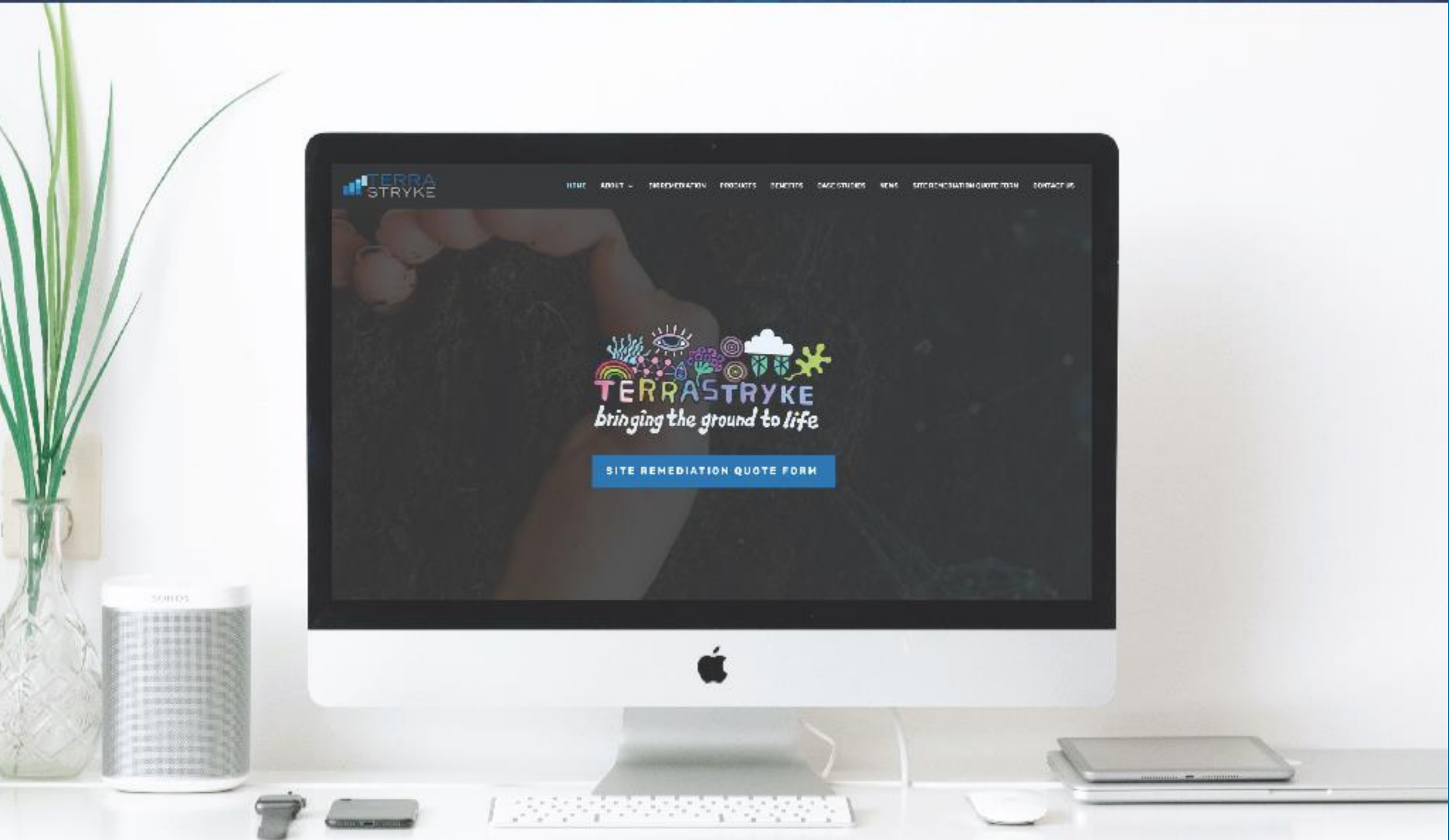


Conclusions

There are lots of options out there



Site Remediation Quote Form



Contact Information

Kent C. Armstrong President

(603) 977-0810 (office)

(603) 731-3159 (cell)

karmstrong@terrastryke.com

284 Depot Street / P.O. Box 254
Andover, New Hampshire USA

950 Fennell Avenue, Suite 105
Hamilton, Ontario CDN L8V 1X2
(905) 387-2255

IF YOU HAVE A
CONTAMINATED SITE THAT
NEEDS CLEANING UP,
REACH OUT TO US!



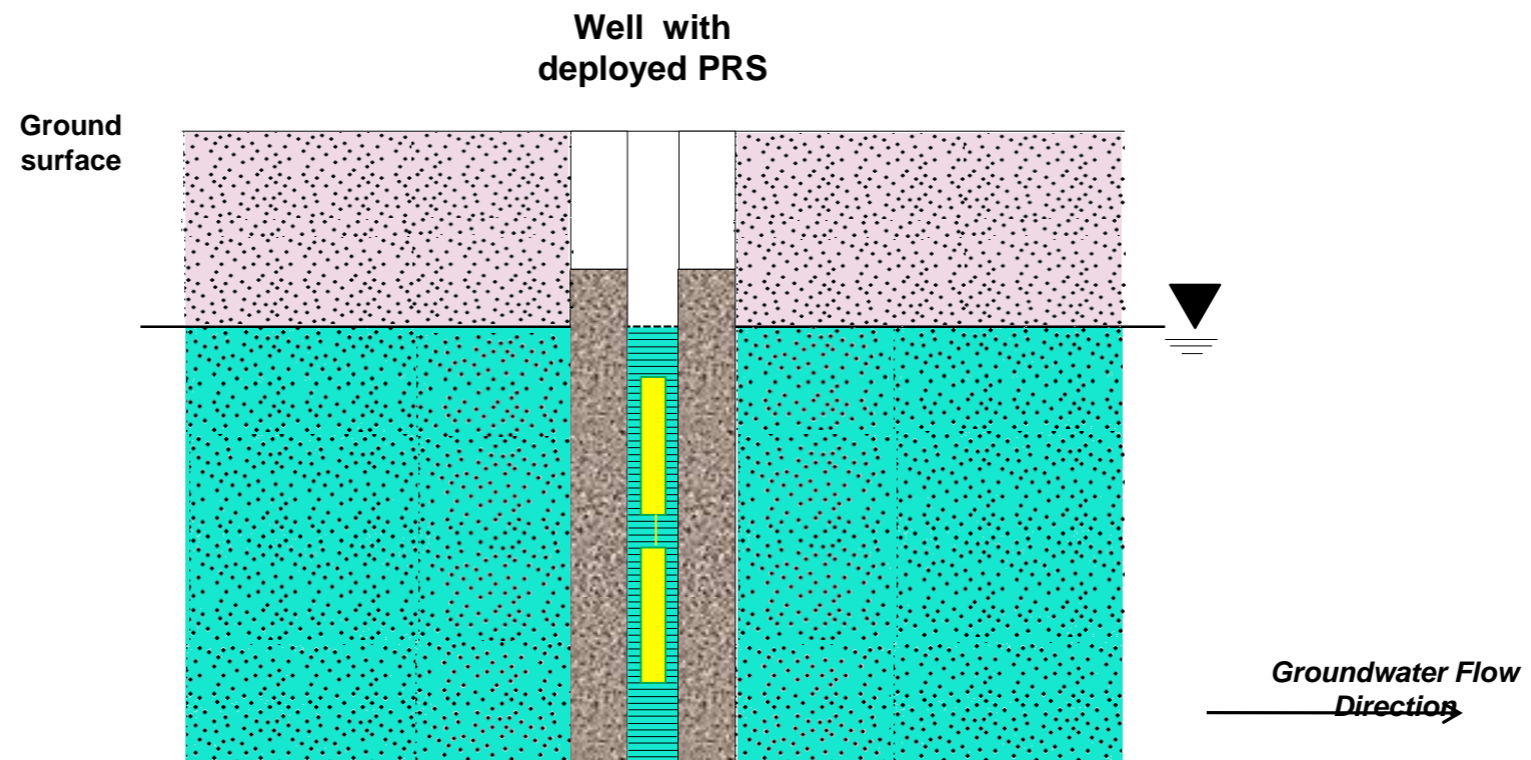
BRINGING THE GROUND TO LIFE. TERRASTRYKE.COM

Passive Release Sock (PRS Deployment Unit)

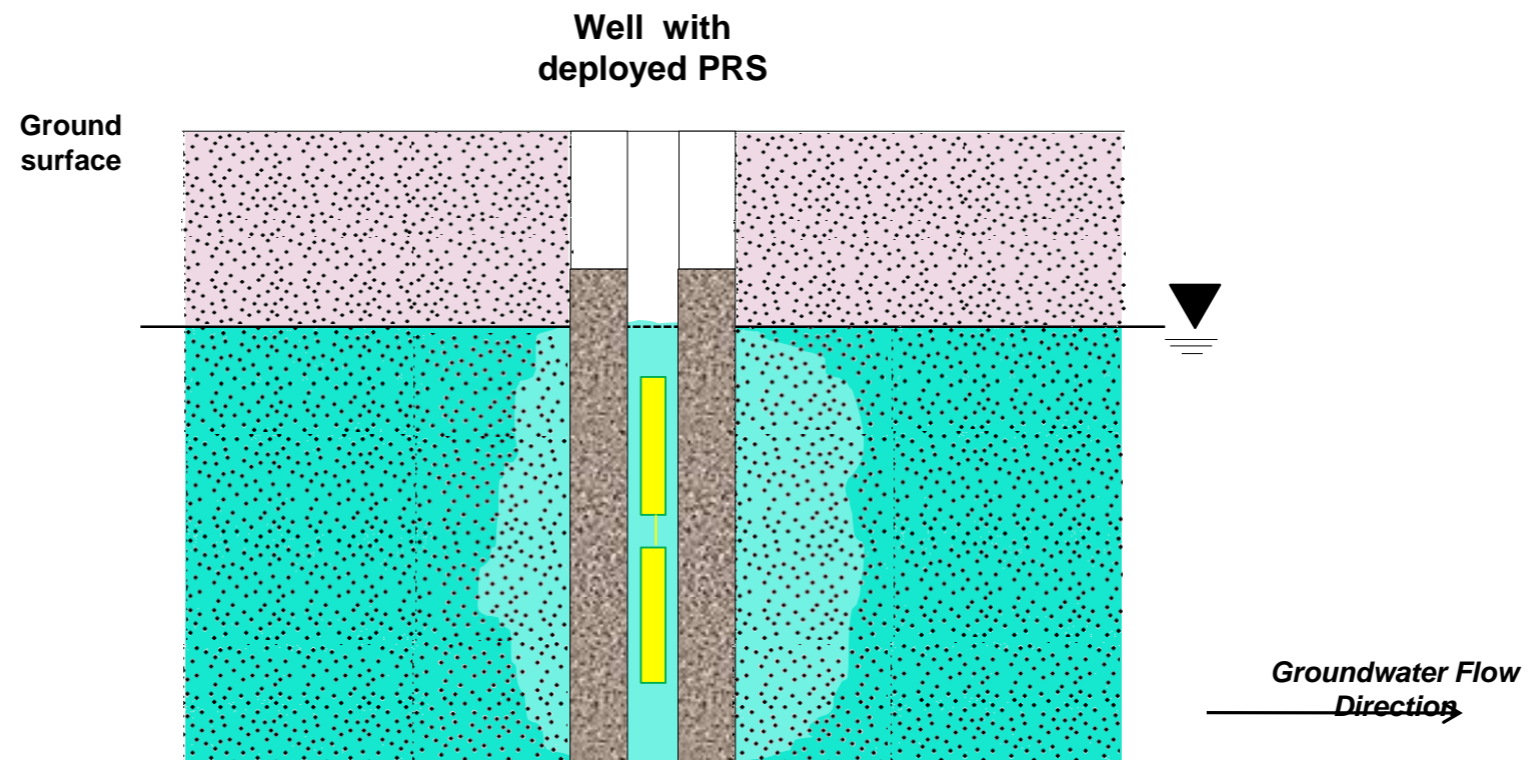
- Low-Cost, Low-Risk On-site Evaluation process
- Fit directly into existing 2-inch GW monitoring well
- Provides Representative '*Go-no-Go*' on-Site Evaluation
- Baseline & Performance Monitoring/Sampling
- Field Indicator Parameters Recorded Every Replacement Event
- ORP, DO, pH, Temp, Cond; NO₃, SO₄, dissolved Mn/Fe; Ethane, Methane, Ethene, and Contaminant of Concern
- Non-purge, low-flow sampling protocols



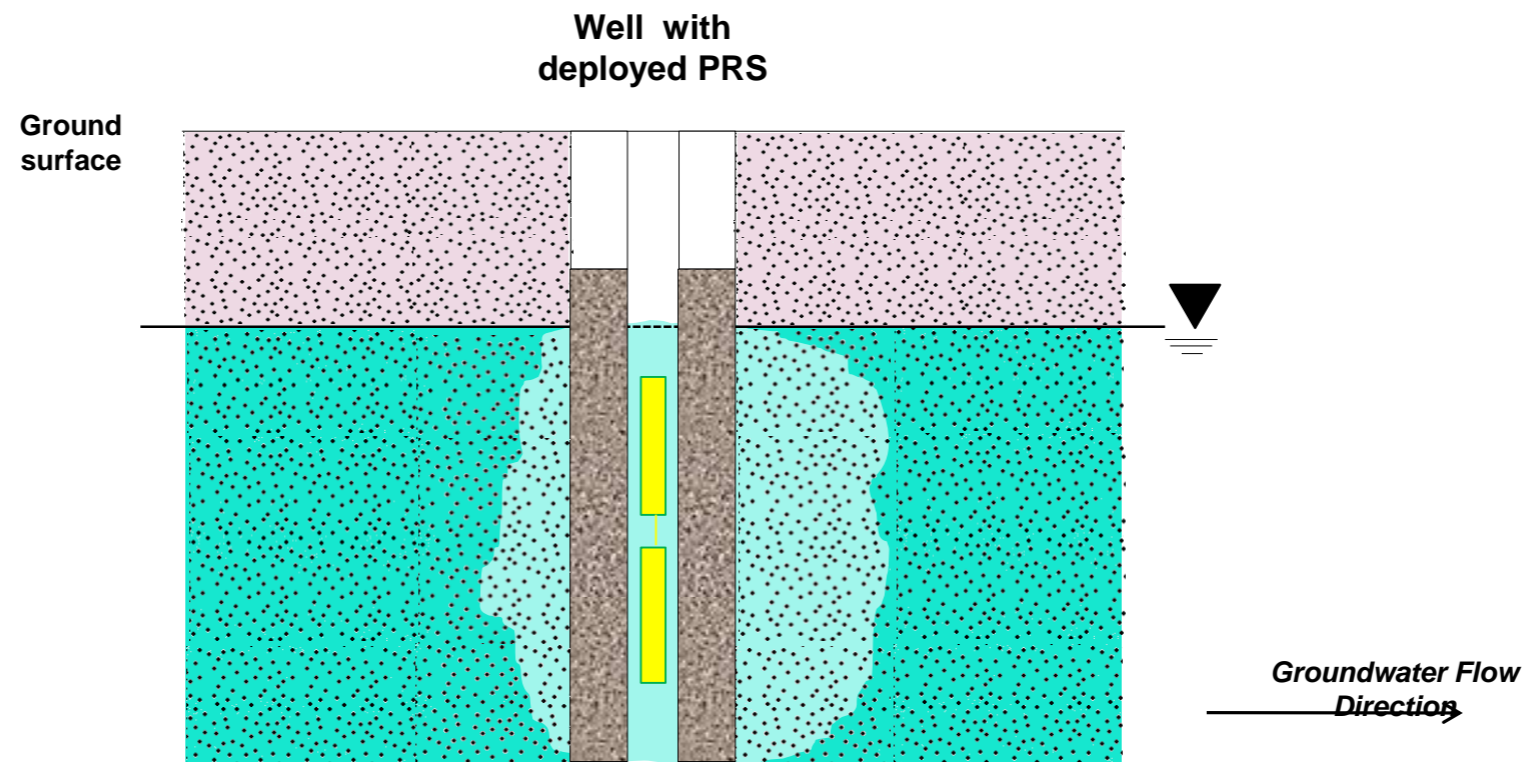
PRS Proof of Concept Study



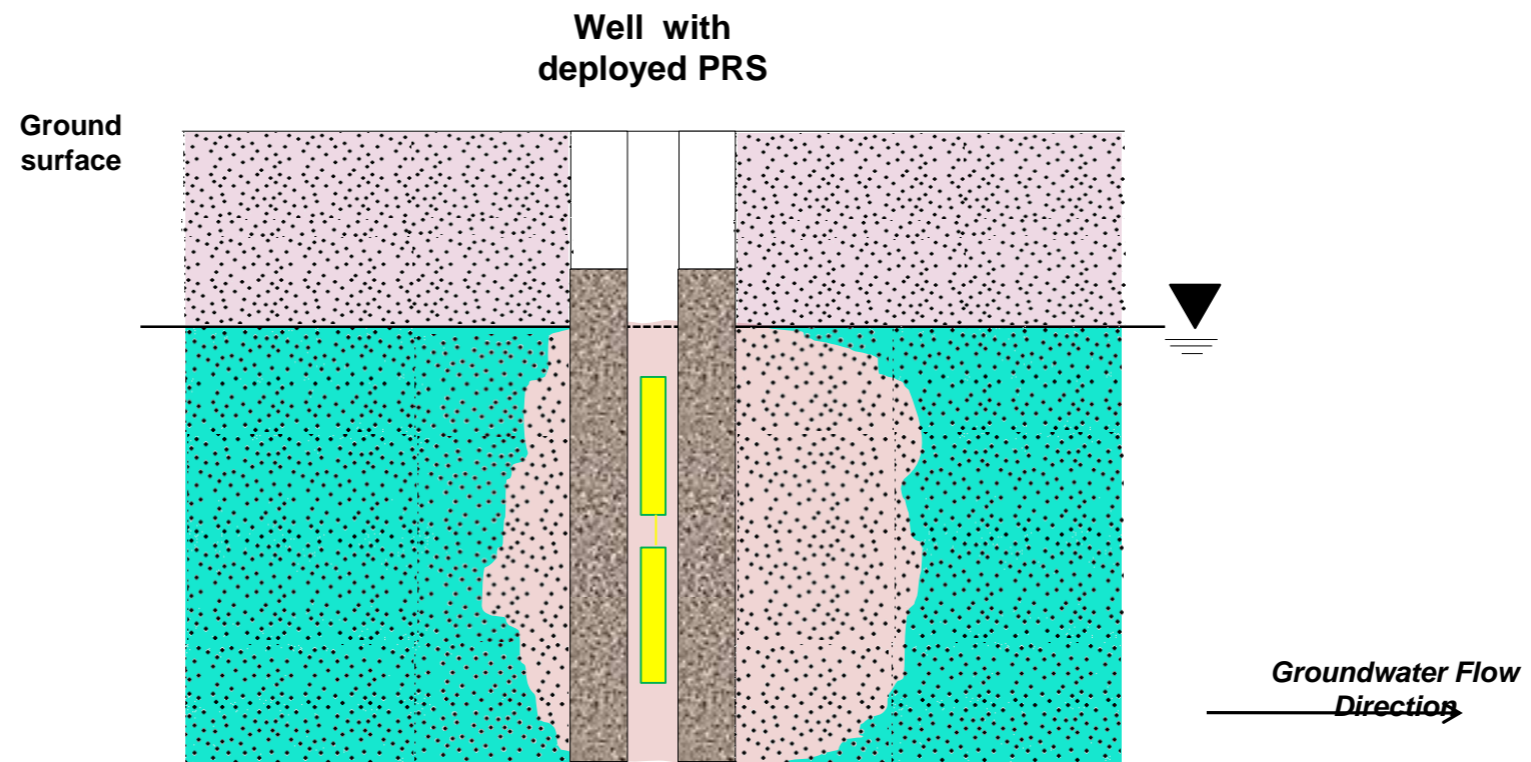
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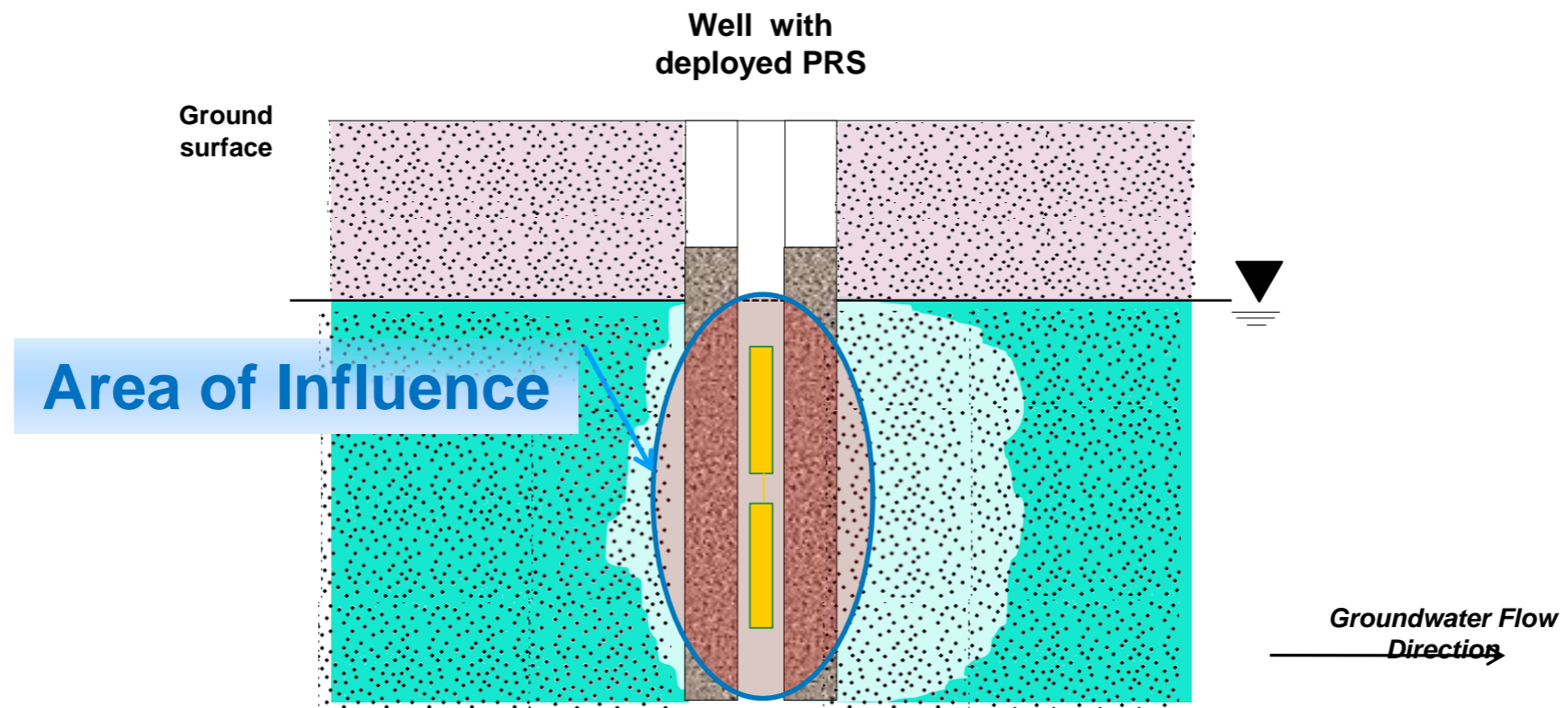
PRS Proof of Concept Study



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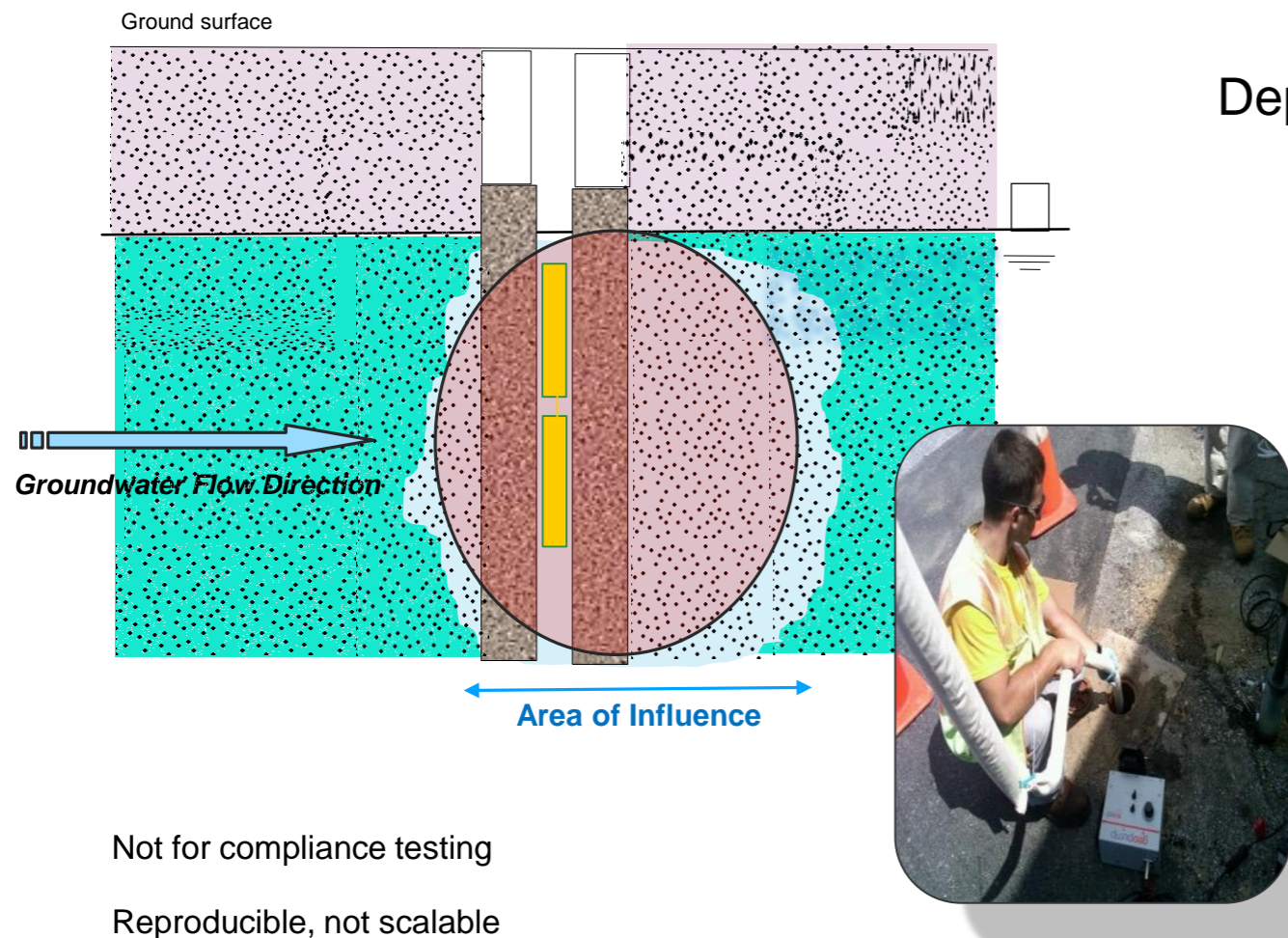


PRS Proof of Concept Study



PRS Proof of Concept Study

PRS Pilot Study Schematic



'Go-no-Go' evaluation
Additive filled Passive Release Sock (PRS)
Deployed into existing 2-inch gw monitoring well

Passively amend saturated screened interval
Create 1-2 meter area-of-influence
Replace PRS units every 6-8 weeks

□ Monitoring Program

- Baseline
- Each replacement event
- Non-purge
- Low-flow
- 6-8 replacement events typical

